The British Rail Total Operations Processing System And the Birth of Telematics

Neil Urquhart

School Of Computing, Engineering and the Built Environment, Edinburgh Napier University.
n.urquhart@napier.ac.uk

***Abstract*—Contemporary mobility is almost universally supported by telecommunications networks and computing facilities known collectively as *telematics*. This has allowed closer integration of freight logistics into supply chains, and supported the growth of the on-demand economy. From a passenger perspective it has allowed real-time journey tracking, planning and re-planning in response to disruption. We examine the design and implementation of the British Rail (BR) Total Operations Processing System and make the case that it pioneered the field of Telematics. When introduced in 1971 TOPS was the first computer system that created a digital model of a complex transportation network, updated in real-time, supporting operation and management activities. Although based on an earlier IBM system, BR expanded TOPS and implemented it into a scenario that was significantly more complex than previous usage in the USA. We argue that the fundamental principles that underpin contemporary telematics systems were established through TOPS.**

***Index Terms*—Rail Transportation, Telematics, Communication, Vehicle Routing, Logistics**

I. Introduction

The field of mobility has become closely linked to the areas of computer science and telecommunications giving rise to the term *Telematics* [1]. Telematics is a portmanteau of Telecommunications and Informatics, it has been applied to systems that combine computing, communications and transportation. Such has been the impact of telematics, that, other than walking or cycling, there are few mobility networks that can operate without support from telematics. Freight networks rely on software for scheduling and consignment tracking [2]. This has lead to the development of responsive delivery services, facilitating the growth of the on-demand economy [3]. Public transport users are supported by real-time information and journey planning systems that can be accessed via smartphone applications. Electronic payments and online booking systems have been widely adopted.

Alongside physical transportation networks have grown communications networks which allow information to flow in advance of movement. Such communication networks began with the use of the Morse telegraph and grew to encompass technologies such as telephones and radio and are now mostly dedicated to the transmission of digital information. The majority of contemporary transportation networks cannot function without the support of their communications network and the computing facilities required to process the data being transmitted.

The development of dedicated telecommunications alongside rail networks, such as that in the United Kingdom, allowed data to travel around the network in advance of trains [4], allowing managers to oversee them with increasing efficiency. A summary of developments is given in [5] . The addition of computing facilities to the communications network allowed the transmission, storage and processing of digital data, supporting the efficient use and management of transportation networks. An early example was the Total Operations Processing System (TOPS) developed in the early 1960s for the Southern Pacific Railroad (SPR) in the USA by IBM [6]. The primary role of TOPS was to allow real-time tracking and management of freight vehicles within the SPR network. SPR and IBM began development of TOPS in 1960 and commenced using it in 1968 [7]. TOPS was subsequently sold to British Rail (BR) who further developed it. TOPS is still in use in the United Kingdom tracking train movements within the rail network.

In this paper we argue that the British Rail implementation of TOPS represented one of the earliest significant instances of a telematics system where a transportation network became reliant on telecommunications and computing, demonstrating significant improvements as a result. TOPS allowed BR to become the first rail operator in Europe to manage freight operations by computer in real-time and arguably a world leader in telematics technology when TOPS was introduced.

A number of primary sources covering TOPS and its development exist, the most useful being Robert Arnott's account of the system procurement and development written from the context of his position as project manager [8]. The memories of Les Smith [9] who worked as a developer on the TOPS system, provide a useful insight into the technicalities of development and deployment. An resource exists in the form of the films created by British Transport Films (BTF) two productions in particular [10] deal with aspects of TOPS and [11], give details of how data was processed prior to TOPS. These contemporary sources allow us a unique view into the manner in which a state of the art computer system was introduced into BR.

II. Contemporary Business Computing Developments

Early computing was primarily the domain of academia and the military , the first private business organisation to

TABLE I
A GLOSSARY OF BRITISH RAILWAY TERMS USED IN THIS PAPER.

Term	Meaning
Wagon	A rail vehicle used for the transporting of freight.
Carriage	A rail vehicle used for the transporting of passengers.
Consist	The set of vehicles that make up a particular train

utilise computing was the British concern of J. Lyons & Co. [12]. Executives at Lyons became aware of the potential of computers to streamline their business and authorised the development of the Lyons' Electronic Office (LEO) in 1951. Lyons established Leo Computers Ltd. which ran software tasks for other organisations. Amongst the early jobs undertaken by Leo Computers. was one for the British Transport Commission, calculating the distance between 7,000 goods stations within the British Railways network, to calculate freight tariffs.

The American company International Business Machines (IBM), a manufacturer of equipment such as punched card readers adapted to the production of computer systems. By the late 1950s IBM began development of the Semi-Automated Business Research Environment (SABRE) in conjunction with American Airlines, going online in 1960. SABRE allowed the real-time reservation of airline seats on American Airlines [13] and was subsequently adopted by other Airlines and remains in use today (2024). A significant aspect of the SABRE system was real-time operation, prior to this most computer systems operated in batch mode. IBM may well have drawn on their experience in developing real-time military systems such as the Semi-Automatic Ground Environment (SAGE) for the United States military. Given that that SP and IBM began development of TOPS in 1960 [6], [7] with the core functionality being the real-time tracking of wagons within the SP network, IBM may well have drawn in their experience of real-time systems development gained with the SABRE and SAGE systems.

III. Railway Operations in the United Kingdom

Railways within the United Kingdom remained in private ownership until nationalisation in 1948 [14] after which they came under the control of the British Transport Commission (BTC) as British Railways and subsequently passed to the British Railways Board (BRB) in 1963 becoming British Rail (BR).

Upon nationalisation the BTC commenced modernisation including the procurement of diesel locomotives and electrification of certain routes. BR found competition from other modes of travel leading to declining passenger numbers and less freight traffic. It became a necessity not just to re-equip the railways, but also to make them more efficient, the most public aspect of this being the appointment of Dr Richard Beeching as chairman of British Railways in 1961 [15]. Beeching is most remembered for his report "The Reshaping of British' Railways" [16] published in 1963 which recommended the removal of services from loss making routes.

Arnott [8] states that investment in rolling stock and infrastructure, including electrification was improving passenger revenue, while BRs' freight business was shrinking. The rationale for the management of freight traffic by a computer system was primarily based on the need to make better use of resources such as locomotives and wagons.

British Railways had prior experience of computing James [17] notes that BR operated "around 60 data processing centers equipped with more than 40 computers", but describes them as "small and of limited range". James goes on to mention that this effort mostly "serves regional needs and inter-Regional use is trifling". James notes that computing would best serve BR when implemented at a national level "consideration must be given to the use of computers on an 'industry' rather than a sectional basis". James makes a strong case for the establishment of larger data centers, but the envisaged uses are mostly based around accounting, stock control and management reporting. James does mention the possibility of automated timetable planning, that being the only suggested application which would appear to be railway specific. James presents evidence that BR was taking computing seriously and senior managers were presumably aware of developments in business computing.

Efforts to establish centralised train control within the UK stem from the Midland Railway Co. (MR) who established district control offices which reported to a centralised control office [5]. The MR system was based on telephone communication from locations across the network to report on train movements to centralised control offices, where trains were represented by cards. The MR system was subsequently passed on to the London Midland and Scottish Railway in 1923 forming the basis of traffic management into the nationalised era. A decentralised manual system was not without its' issues, Arnott [8] recounts that that while it would be known when a train was due to arrive at a yard, it was not known what would be the consist of the train. The adoption of Telex communications the 1950s supported a development named Advanced Traffic Information (ATI). Main marshalling yards were equipped with telex machines, allowing details of a train consist to be sent in advance. ATI and the earlier MR system, were examples of information networks allowing more effective control of a physical transportation network. Despite these developments, Fiennes [18] recounts that in the pre-TOPS era BR had to resort to offering rewards to staff in order to trace wagons containing valuable cargo that had been "lost" within the rail network. The documentary film Train Time [11] demonstrates the pre-TOPS methods of organising and managing rail traffic within the UK.

Subsequent to ATI, a computerised freight management system named Continuous Progress Control (CPC) was trialled on the Cardiff district of British Railways[19]. Whilst TOPS tracked individual freight vehicles, CPC worked on wagon counts, it noted the quantity of wagons, by type, at specific locations. CPC was designed as a manual system, but was then implemented on an English Electric computer in 1962. Shelley [19] estimates that CPC lead to a reduction of around 4,000 wagons. In conversation with the author, some ex-British Railways managers suggested that a lack of error checking allowed inaccurate data to be entered, leading to CPC containing an inaccurate model of the current traffic situation, reducing the trust that staff were willing to place on the output from it.

The MR control system [5] and subsequent developments with ATI and CPC were all based around the concept of train management rather than monitoring and controlling of individual vehicles, which only became a realistic proposition with the development of more powerful computer systems.

It can be seen through contemporary sources [17] [19] that BR had experience of computing in a number of fields and through CPC had gained an insight into the possible savings to be made by the use of computers to manage freight operations. CPC was a small scale operation, but ATI showed the value of being able to share operating data electronically across a wider geographical operating area.

The reader should be aware of specialist terminology used within the railway industry, in particular the differences between American and British terminology, table I is provided to assist the reader in this aspect.

IV. The TOPS System

A. Computing Background

Computing technology in the late 1960s was significantly less ubiquitous than today (2023), many individuals would never have seen a computer let alone interacted with one, computing was based around mainframe systems requiring a suite of rooms for installation. Table II gives some idea as to contemporary computing practices (late 1960s) versus the work undertaken by TOPS.

Operating in real-time, at any given moment TOPS would contain the status of the rail network, comprising location of rolling stock (freight wagons and all locomotives) and and the status of all trains currently running. A typical late 1960s computing application would be payroll where data on hours worked by employees was collected, stored on punched cards or magnetic tape, before the programme was executed to determine the amount due to each employee. Typically such an application would have been executed once per week. TOPS represented a departure from this batch processing pattern, the TOPS mainframe would be responding in real-time (i.e. immediately) to train movements and staff enquiries. Although the TOPS mainframe installation was located in London, TOPS was designed to be accessed from locations across the UK. This was made possible by the telecommunications network that had been built by British Railways for its own use [10].

Computer literacy was not a skill possessed by many, if TOPS was to operate successfully many BR employees across the UK would need to interact with TOPS on a daily basis. Some of those staff would be clerical grades, but many would be based in marshaling yards or motive power depots. Not only would these staff need to be able to update TOPS and to interpret its output, they would also need to trust the integrity of the system to make operational decisions based on its output.

B. TOPS Procurement

The TOPS procurement process commenced with an examination of developments elsewhere [8] such as France, West Germany and Japan. The German system, developed by Siemens [20] was discounted, Arnott describing it as a ”... computer technician’s delight in its ever-increasing sophistication”. None of the European or Japanese systems matched BRs requirements, so the search continued across the Atlantic. The Canadian National Railroad (CN) was implementing its TRACS system [21] which recorded the status of rolling stock in real-time and was based upon the IBM/SPR TOPS. Of the systems examined TOPS was the only one which it was felt matched British Railways requirements [8].

A controversial aspect of the decision to procure TOPS was that both the software and hardware were sourced from America despite the United Kingdom having a domestic computing industry. There was precedent for British Railways procurement being used to provide stimulus to British industry, during the transition to diesel traction in the 1950s [22], [23] orders for many different types of locomotive were placed with British suppliers. Non-UK manufacturers (especially US ones) had considerable experience of Diesel Electric locomotive construction, but in order to support domestic industry, BR ordered its fleet from British suppliers. This policy lead to the purchase of many designs of locomotive, some of which were so unfit for purpose they were scrapped after only a few years use [24]. It is not known whether these experiences influenced the decision to purchase TOPS from the USA, but project manager Robert Arnott is quoted as stating ”.. speed was the essence - worth swallowing any national pride for.” [8]. It should be noted that the UK-based International Computers Limited (ICL) were invited to submit a proposal to British Railways [8]. The proposed ICL system would take at least 6 years to implement, whereas TOPS was based on software already developed and in use. The ICL proposal was unsuccessful and British Railways opted to procure TOPS software and hardware from the USA.

One question that might be asked in retrospect is could BR have bought British hardware to run the TOPS software? To answer this question we need to have some understanding of computer systems. From the 1970s and 80s onward, general practice has been for computers to run an operating system and for applications software to be written for the operating system rather than the underlying hardware. When TOPS was implemented in the early 1960s, applications software was, written for a specific manufacturers architecture. In this case TOPS was based around IBM architecture and could only be run on IBM mainframes. To allow TOPS to run on another manufacturer’s hardware (e.g. ICL) would have necessitated redevelopment of the software - precisely the task that BR wished to avoid.

Authorisation for BR to procure the TOPS software and hardware was given on the 6th of October 1971, by the then Minister for Transport Industries, John Peyton.

C. TOPS Hardware

TOPS ran on IBM 370/168 mainframe computers, two of which were located at the Blandford House Computer Centre (BHCC), London, one ran the live TOPS system, the second being available to take over should the first machine fail [8].

TABLE II
TOPS DIFFERED DRAMATICALLY FROM CONTEMPORARY (1960S) COMPUTING INSTALLATIONS, AS IT WAS INTENDED TO MANAGE IN REAL-TIME A RAILWAY NETWORK SPREAD OVER A LARGE GEOGRAPHICAL AREA.

	Contemporary (late 1960s) Practice	**TOPS**
Processing Mode	Batch processing of data. Data is typically stored and then processed when a specific program is executed	System updates in real time to respond to real-world events, e.g. train movements or customer requests
Geographical Area	Mainframe based systems usually connected directly to peripherals (terminals card readers etc) located on thes ame site. Communication between sites very rare.	The central TOPS computer communicates in real time with terminals locates in TOPS offices across the United Kingdom
Users	Most users of computers are specially trained, very few people directly interact with the computer system.	Many British Rail employees at all levels interact directly with TOPS.

Storage was on 4 IBM 3330 disk drive units which could be connected to either of the 370/168 computers.

The mainframe at the BHCC was directly linked to 152 Area Freight Centers (AFC) located across the UK. Each AFC was responsible for keeping TOPS updated about train movements within its geographical area, the staff working in the AFCs were direct users of TOPS.

In line with the practice on the Southern Pacific, the AFCs were initially equipped with IBM 1050 terminal equipment based around punched cards, although they could also be equipped with a keyboard and tele-printer (the IBM 1050 range did not include a visual display unit). It was quickly found the IBM punched card readers/punches were unable to cope with the amount of dust found at the locations where the AFCs were located [8], [9]. It could also be argued that by 1971 a punched card driven system was no longer state of the art.

BR deviated from SP practice and developed a new software and hardware system for the AFCs based around more robust punched card equipment and a Datapoint 2200 minicomputer [10]. Over 400 Datapoint 2200 minicomputers were purchased in order equip the AFC offices [1]. Each Datapoint system was equipped with 12K of memory, keyboard, a visual display unit and printer. Tape drives were also provided to allow the minicomputer to load its own software.

As TOPS software on the mainframe was designed to communicate with IBM hardware, it was feared that BR might have to extensively modify the TOPS system software [8] to communicate with the new AFC equipment. A solution was found by programming the Datapoint minicompters to communicate in the same manner as the IBM equipment, no changes being required to the software running on the mainframe. This development of the ”front end” software by BR represented a considerable enhancement to the original TOPS system. Having software that allowed the AFC equipment to emulate the original IBM terminals, has allowed BR and successors to develop systems around TOPS without having to extensively modify the original IBM software. Currently TOPS software is communicating with the rest of the UK railway IT software and hardware via standards that assume data is being input and output on punched cards.

Within the area managed by an AFC there could be many sites where freight would be sent and received from, communication between these sites and the AFC would be crucial to the successful implementation of TOPS. Those sites that handled small amounts of freight could use a telephone to communicate with the AFC (see [25]), but facsimile machines were installed at AFCs and at the busier sites, allowing train consists to be handwritten at the site and sent to the AFC [8].

In addition to the AFCs Dyer [26] also notes that BR area managers were provided with a TOPS terminal, allowing the increased use of TOPS supplied data in support of management decision making.

TOPS required over 400,000km of data communications circuits to provide UK wide communication, as well as around 3,000 telephones, 650 uhf radios and 500 facsimile machines [26], [10]. In this respect British Railways was well prepared, it owned a modern communications network which linked London to most major cities in the UK. Railways had been early adopters of telegraphs for communication and British railway companies had developed their own, private phone networks during the early 20th century. In order to manage this communications network a Communications Data Control (CDC) was established at Blandford House to allow 24/7 monitoring of the communications network [8]. Some communications circuits were leased from the then UK telephone operator (the General Post Office) particularly for reaching customer sites.

D. Development and Cutover

Arnott [8] notes that prior to the final decision being taken to purchase TOPS, consideration was given to only covering the busiest areas of the BR network with TOPS. The decision was subsequently taken to apply TOPS to the entire BR network, not least because there would be comparatively few savings in costs by not installing it over more lightly used areas.

The process of rolling out TOPS to the British Rail network was referred to as ”Cutover”. It would have been technically possible to have had the entire BR network adopt TOPS on the same day, but in practice the cutover was to take place over time. Cutover commenced in the south west of England and subsequently moved northwards. The reasons for this gradual cutover are given by Smith [9] as:

- The staff training workload could be spread out
- Any technical issues would affect a smaller number of users

[1]Oberhauser, Joe. Personal Communication.

- The system workload was gradually increased up over time
- All of the data did not need to be loaded and validated before the system went live

Smith notes that prior to the commencement of cutover, estimations had been made as to the computing power required to run the system. At the time a single IBM 370/168 mainframe was estimated to be capable of running the entire BR TOPS system. As the cutover progressed across the UK and neared Birmingham, Smith notes that the processing loads on the computer were higher than had been estimated. There was, it seems, a concern that a single mainframe would not be able to cope with the processing load. To address this another IBM machine was acquired (a 370/158) which would take over some of the TOPS processing. In the event Smith notes that the actual problem was a temporary increase in TOPS usage as new users were added. Such users were likely to make mistakes and repeat transactions as well as trying out the capabilities of the system, resulting in the load increasing during cutover. In the end, Smith notes, a single IBM 370/168 mainframe was sufficient to run the entire BR TOPS system. Staff for TOPS implementation came from a variety of sources, some were existing BR staff who were retrained as analysts/developers (see [9]), others may have been recruited from existing BR computing projects (see [17]).

In addition to the centralised TOPS implementation team, regional teams (based on BR's geographic regions) were established to manage the detail of implementation, including the arrangements for communications (data, voice and fax) to be provided to AFCs and major customers.

Arnott [8] notes that during cutover a temporary interface was setup that allowed ATI telex messages (see section III) to be transferred onto TOPS. When an ATI telex message was being sent from the non-TOPS area to a destination within the TOPS area, the telex was re-routed to a Central Interface Office at TOPS HQ. When a message was sent by telex, each character was encoded as a binary number, the message being sent down a telephone line as a series of tones. This was essentially the same mechanism that was used for sending data between computers (although the binary encoding system used by ATI was likely to have differed from that used by TOPS). The ATI messages were routed to a Ventek terminal (as used in the AFC offices) which was programmed to translate the ATI telex message into the appropriate TOPS message. When communicating the opposite direction a TOPS message was sent to the Ventek terminal in the Interface Office, which was programmed to dial the appropriate ATI telex machine and re-transmit the message as a telex. This solution, which Arnott describes in detail, allowed data to flow between the old and new systems. When TOPS covered the entire BR network by 1975 [27], Smith [9] noting that an estimated 200K messages per day were being processed.

As initially configured TOPS managed the operation of freight traffic, it was implemented alongside the RAil VEhicle Records System (RAVERS) a mainframe based database that coordinated locomotive engineering activities. Subsequently BR expanded TOPS to include the Passenger Operations Information System (POIS) which expanded TOPS to record the movement of passenger trains as well. The running of passenger trains was recorded within TOPS by the train ID (which allowed staff to identify the actual service being operated), TOPS would record the allocation of locomotives to passenger trains and monitor their progress, individual passenger coaches were not recorded within TOPS.

E. *Differences from Southern Pacific*

Many differences existed between BR and SP, the most fundamental differences were based around SP being a privately owned system that primarily operated freight trains. Conversely, BR was state owned with an intensive passenger network as well as freight. SP exchanged goods wagons with other North American railroads (which were not TOPS users) at multiple locations, BR on the other hand was almost entirely self contained, the principle exception being a small amount of vehicles exchanged with Continental Europe via the cross-channel train ferry.

The operations of SP were less intensive than those of BR, SP operating fewer services (with far fewer passenger trains). Practice on SP allowed trains recorded on TOPS to map to several actual trains following each other over the same route [8]. For example, if SP operated a service running from yard A to yard B and the number of wagons allocated was greater then the capacity of a single train, a second would be operated, following shortly after the first. In SP TOPS only one movement would be recorded, even though multiple trains had operated. BR did not have the flexibility to run many additional trains (due to the intensive service of timetabled passenger trains) generally, each freight train on BR was individually scheduled and entered into TOPS. This lead to the BR version of TOPS handling far more daily trains (approx. 3,000) it was estimated that 1 SP train on TOPS could represent between 40 and 50 BR trains [8].

Arnott [8] notes that changes were required to TOPS to take account of the fact that BR operated many classes of locomotive, each class having specific maintenance requirements. To further complicate matters some classes could not work with others where multiple locomotives were required to work the same train. If two incompatible types were used on the same train then a crew was required in each locomotive. BR also had three braking systems, many freight vehicles had no brakes at all (stemming from Victorian practice) and relied on the locomotive and guards van (caboose in North American practice) to control the train. Where brakes were fitted they could be either vacuum or air operated systems. Within the BR scenario TOPS had to take into account the additional constraints imposed by these braking systems when determining the consist of a train to ensure that it contained compatible vehicles.

The exact size of the BR wagon fleet was unknown prior to TOPS implementation [9], this situation had come about due to BR having been formed from four companies, which were themselves groupings of smaller companies. Each constituent company had possessed their own fleet of wagons, recorded on their own paper-based records system. It was not until TOPS that this wagon fleet was recorded in a single centralised database. The BR version of TOPS had to be able to record the differences in the many wagon types and ensure that the correct type of wagon was allocated for the conveyance of a cargo.

The above highlights operational differences between SP and BR, however from a software engineering perspective there were many fundamental similarities. Both systems operated trains which were hauled by locomotives which conveyed a consist of wagons between points on the network. Customers generated traffic which required suitable wagons to be identified, moved to the customer and then transported within one or more trains through the rail network to their destination.

F. TOPS Operation

On BR the operational management of TOPS was dealt with by the TOPS Online Control (TOC) [8] whose staff provided support to users' across the BR network. The BR network was initially divided into 152 TOPS Responsibility Areas (TRAs), each area encompassing a certain amount of freight activity. An effort was made to ensure that short distance freight trips were operated within a single TRA. Each TRA contained an Area Freight Center (AFC) office to allow access to the TOPS mainframe. Arnott [8] notes that the the boundaries of the TRAs were set based on freight traffic flows and as far as possible were not influenced by existing administrative boundaries.

At any time, TOPS contains a snapshot of the current status of the BR network including the location and status of rolling stock. This snapshot exists on the TOPS mainframe within a set of files.

- Wagon file
- Yard (Terminal) file
- Destination file
- Locomotive file

Within these four dynamic files TOPS stores the status and location of every wagon and locomotive on the UK railway network in real-time and the status of all trains. These files hold a snapshot of the network, as they are updated so previous states are lost. Journal files are appended as TOPS is updated, over time the journal files make up a record of past activity within the system.

TOPS maintains journal files for:

- Arrivals
- Interchanges
- Yard Activity
- Train Activity
- Locomotive Activity
- Wagon Activity

Initially (1975) TOPS data was stored for 8 weeks [27] in order to allow for retrospective enquiries on topics such as missing or damaged freight. Data from the journal files was used to produce management reports on the performance of the BR network. Thus TOPS supported not only operational decisions related to the real-time movement of trains, but also through the collation of journal-based data which could be used to highlight longer-term trends in activity.

The AFC installations [25] were based on a punched card representation of the area that they were responsible for. Each locomotive or wagon within the AFC's domain was represented by a punched card. Physical locations are represented by racks containing cards. The detailed representation of the AFCs area was therefore modelled in a physical system of racks and cards. We may speculate that part of the reason why TOPS was adopted with apparent ease by operational railway staff, was that the AFCs primarily used this physical model which would have been easily understood by operational staff. For example if wagon 1234 was shunted from siding A to siding B then this would been recorded by moving the card representing wagon 1234 from the position in the rack representing siding A to that representing siding B. When a freight train is prepared for departure, a deck of punched cards recording the consist of the train and its schedule were fed through the card reader [25]. Each wagon within the train is represented by one card containing the wagon number, type, load and destination [10]. When the train cards have been read a train list is printed, this includes the overall length, weight and braking characteristics of the train which are calculated based on the consist [10]. This generates a message which is sent to the TOPS mainframe, triggering the execution of an application program. The program uses data from within the message and to update the dynamic files and where necessary add entries to the journal files.

When the mainframe is notified of a train departure, a message is sent to the destination AFC which results in a train list and set of punched cards printed out in anticipation of the arrival of the train [10]. The destination AFC is aware when a train is en-route and the consist of that train.

The fundamental task of TOPS was to track and manage the BR freight wagon fleet in real time, this being achieved by having an entry in the wagon file for each wagon on the network. Within each entry the wagons' status and current location were recorded. Status was recorded as in transit or in location. If wagon was stationary at a location then a TOPS location code was assigned as its location, if it was part of a train consist then the train schedule identifier was assigned as the location. More detailed status codes could also be used to note that the wagon was empty, loaded, awaiting unloading or needing repair etc. By keeping the wagon location and status fields up to date the status of the entire wagon fleet was recorded [8]. Thus TOPS allowed BR to move from a situation, where it had no complete record of the wagon fleet, to one where it knew, in real-time, the location and status of every wagon.

An interesting aspect of TOPS was the management of sensitive consignments, such as high value goods or explosives. Such consignments were "disguised" within the system to ensure that the minimum number of staff knew where such consignments were within the BR network [27].

One of the most computationally complex aspect of TOPS is that of wagon routing. For many consignments there may not be a single train that operates directly between the origin and destination locations. Each location was allocated a unique ID (known as a *STANNOX* ID) to identify it within TOPS. Around 10,000 STANNOX locations are still recorded as in use within the former BR network, this equates to over 99m possible origin destination pairs, each requiring a route. Compare this to the 7,000 goods stations used in the earlier exercise undertaken by LEO for the BTC (see section II) - presumably STANNOX codes were allocated to many locations other than goods stations. Software algorithms capable of finding routes through transportation networks have been in existence since the late 1950s [28], [29] and contemporary software systems such as Google Maps provide on-demand routing services through very large road networks. In the early 1970s it would not have been feasible to have calculated routes through a 10,000 node network in real-time, nor would it have been feasible to pre-compute 99m routes and store them for later use. It is interesting to review this aspect of TOPS from a contemporary software engineering perspective. Based on the description in [8] we can describe the methods used within TOPS. Firstly TOPS introduces a hierarchical form of approach, although there were around 10,000 STANOX codes between which routing could be required, they could be abstracted to the 89 TRAs. Country-wide routing may be carried out on between the 89 TRAs, assuming that the routes are reversible that gives 3,916 possible routes. This hierarchical approach which sees a large routing problem simplified by having the routing take place over a much simpler network at a higher level is a fundamental part of current routing algorithms [30]. Contemporary vehicle routing algorithms often use a nationwide motorway network as the higher level, the motorway network being far simpler than the complete road network, but still linking most major cities.

When a single wagon or group of wagons is required to be transported across the rail network the wagons are allocated a 3-digit tag number, this indicates the next destination of the wagon. The first two digits of the tag represent the identity of the AFC, the third a specific location within the AFC area. It can be surmised that the first two digits will determine the train service that will be used to move the wagon to the next area and the third digit indicates where the wagon should be placed on arrival. As the wagon arrives at each intermediate destination, the tag is updated to show the next stage of the journey. Thus if a wagon has to travel by three intermediate marshalling yards in order to be correctly routed then the tag will be updated on arrival at each of the three intermediate marshalling yards. It is useful to examine the decision making being made by TOPS when the wagon arrives at each intermediate point a decision must be made as to which tag to allocate to the wagon next. If the STANNOX codes were used as the basis for routing then the STANNOX code would have to be looked up and the associated tag allocated. For each intermediate location the list of 10,000 STANNOX codes and tags would need to be maintained for every possible intermediate location. By using AFC areas, TOPS only has 89 possible tags to allocate to each wagon, which massively simplifies the problem. A series of TAG codes in the range 9xx were reserved for local use, when a wagon arrived in the destination area such local tags were used to describe the final movements within that area to ensure that the wagon was correctly shunted to its destination. This routing technique is broadly similar to that of routing/forwarding tables used in networking devices such as routers which are responsible for determining the path taken by individual data packets across the internet, which are contemporary to TOPS [2]. The updating of train, locomotive and wagon details in real-time comprised the input to TOPS that allowed it to ensure that its files contained an accurate reflection of the current state of the BR network. In order for BR to gain any value from these activities it is necessary to be able to query the model. In the film ”Using TOPS”, [25] we see the system being queried a number of times:

- To find the nearest available wagon that meets a customers’ requirements
- To find the sequence of trains required to route a wagon from pickup to delivery
- To find a wagon that is carrying a consist within the network and arrange for it to be diverted to new destination

The ability to answer queries such as these ensured that staff are better informed about the location and availability of resources allowing them to make more efficient decisions.

A major aspect of railway freight operations is the redistribution of empty wagons [18], [8]. When a wagon has been utilised on a delivery the decision must be taken as to where to move the wagon in preparation for its next task. Traditionally [11] empty wagons were collected at marshalling yards and their quantities sent to central controllers who would attempt to dispatch empty wagons to those areas requiring them. It may be surmised that it was in this area that many of the operational inefficiencies existed.

Given that British Railways was primarily managed along regional structures (very much based upon the previous operating areas of the constituent railway companies), it is likely that such decision making would be localised and lead to duplication of wagons across the network. Within TOPS an application was provided [8] that would manage the distribution of empty wagons. This application was based not on SP TOPS but was supplied by the Canadian National Railroad [21] having been developed as part of their TRACS system. Analysts identified 325 demand units (DU) locations within the BR network which required a regular (6 wagons or more per day) supply of empty wagons. The requirements of each DU were established based on the previous 7 day average. The system would allocate sufficient empty wagons to be routed to the DU in order to meet this requirement. At the time of TOPS implementation there were an estimated 270 [8] wagon types used in British Railways were grouped into 29 categories for distribution. The system ensured that the correct category of wagon was sent. Where empty wagons were not required for routing to a DU they would be sent to a default holding point to await further use. In addition, wagons could be manually requested and dispatched to a customer [25].

V. Conclusions

A. *Contemporary Effects of Introducing TOPS*

By 1975 British Rail was suggesting that £3 million per year in operating costs would be saved by utilising TOPS [27]

[2]Computer Networking History, https://www.computerhope.com/history/network.htm, Last accessed 19/03/2024

and that 50,000 freight wagons were to be disposed of due to the implementation of TOPS. This was against a background of little government investment in British Rail, indeed as late as 1983 a government commissioned report [31] into railway finances included the option of closing around 84% of BRs route millage.

Table III shows that although BRs freight revenue fell in the the period 1975 to 1982, it's profits grew from losses in 1975/76. Some of this can attributed to more efficient control of resources. Figure 1 shows that the BR wagon fleet had shrunk by over 100,000 wagons between 1974 and 1979, during the same period the operational cost per mile dropped from 1.77 to 1.58 (figure 2). Some of the reasons for this increased profitability may be found in figure 4 which shows the average amount of freight carried per each train increasing, after TOPS was introduced. These figures all point to BR carrying less freight, but doing so more efficiently in the years following the roll out of TOPS.

When asked in 1971, whether TOPS was worth the investment a BR spokesperson was quoted as stating "TOPS is the price of staying in the freight business" [7]. If one thinks that the phrase "staying in the freight business" was being over dramatic, then figure 3 illustrates the downward trend in BRs' freight business. TOPS was not without its critics, in 1971 New Scientist magazine [7] asked the question "Is this complexity really necessary?" when describing TOPS. In the same article it was pointed out that although TOPS was developed in the USA "most US railways have steered clear of the system".

It would be unfair to give the impression that BR simply purchased a ready made system that was just installed and used. Contemporary accounts show that TOPS required considerable innovative adaptation for BR use [8], [9]. One area that BR developed extensively was the arrangements used in the AFCs. Whilst SP used IBM punched card hardware, BR developed a minicomputer based solution that gave each AFC its own computer system, allowing cardless TOPS to be adopted. Anecdotal evidence suggests that some AFCs were still using punched cards well into the 1980s. One has to assume that by the time AFCs were upgraded to cardless TOPS staff would have been sufficiently familiar with TOPS and computing concepts to adapt. It is interesting to speculate as to whether the adoption of a cardless system from the initial installation point might have resulted in far more issues with staff acceptance of the system. A cardless system would have been technically possible in the early 1970s, and indeed if a bespoke system had been developed for BR then there is a reasonable chance that it might not have used punched cards.

Fiennes [18] recounts the labour intensive nature of the pre-tops system involving manual counting of empty wagons and the submission of statistics as well as manual searches within marshalling yards for wagons which had not been received at their destinations, the advantages of having TOPS monitoring freight traffic and wagon status in real-time are all the more evident. Arnott [8] recounts that "the most spectacular" output from TOPS was the Daily Distribution Report which gave a snapshot of requirements for empty wagons, those available at specific locations and those in transit. This report allowed BR to efficiently control the distribution of wagons and increase their usage. The routing capabilities of TOPS are impressive, and may well represent one of the earliest attempts to solve a large scale path finding problem outside of the field of computer networking. Given the involvement of IBM in the development of networking techniques in the 1960s it may well be that the TOPS routing system was directly inspired by developments in that area.

If the reader doubts the technical significance of TOPS then it is worth noting that the TOPS mainframe software has proven so reliable and fit for purpose that in 2021 it is still running and still records the state of the UK rail network in real time.

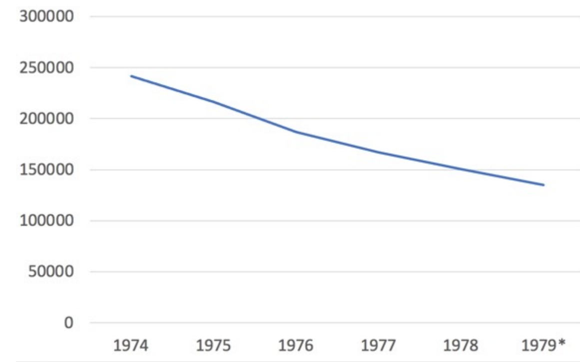

Fig. 1. The size of the BR wagon fleet in the years after the introduction of TOPS. Taken from [8], note that the figure for 1979 is a contemporary estimate.

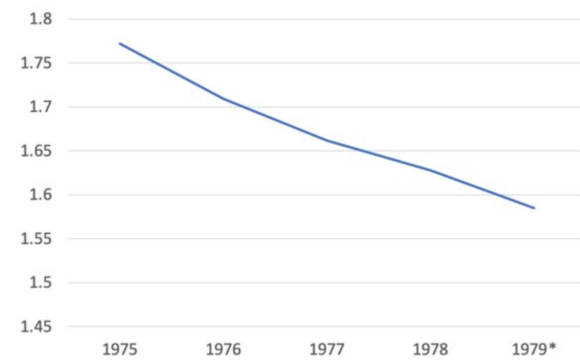

Fig. 2. The BR operational cost per mile, following TOPS implementation. Taken from [8], note that the figure for 1979 is a contemporary estimate.

B. The Legacy of TOPS

TOPS is still a vital component of the United Kingdom's transport infrastructure. In the late 1960s when BR first realised that computer control could provide efficiency improvements, the UK rail network was still very much a Victorian railway that was only just dispensing with the steam locomotive. It can be argued that British Railways re-invented itself during the late 1960s early 1970s. Alongside TOPS BR also undertook significant research and development which resulted in the immensely successful High Speed Diesel Train (HSDT) which, marketed as the Inter-City 125, improved the image of rail travel. The role played by TOPS in this era is one that this not as obvious to BRs' passengers, but should have been obvious to BRs' freight customers.

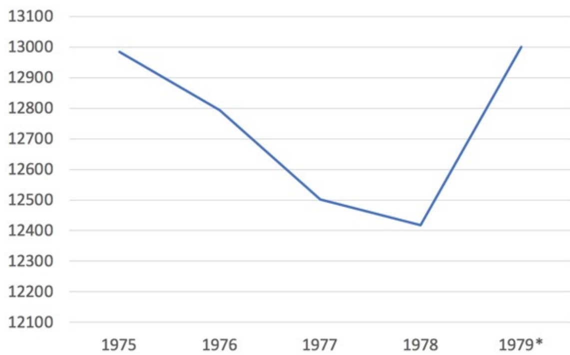

Fig. 3. The tonne miles of freight carried by BR following TOPS implementation. Taken from [8], note that the figure for 1979 is a contemporary estimate.

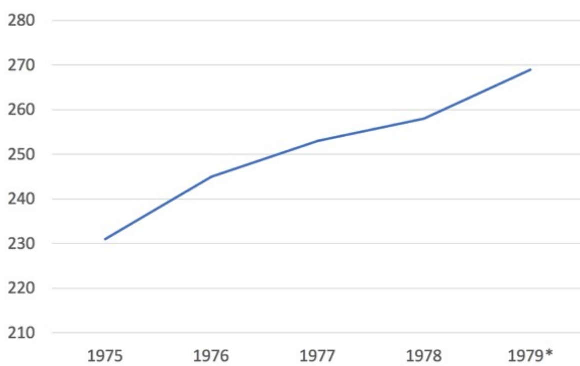

Fig. 4. The average payload per freight train. Taken from [8], note that the figure for 1979 is a contemporary estimate.

The developments outlined in table II demonstrate the argument that TOPS was significantly ahead of contemporary technical developments. TOPS was built upon an existing telecommunications infrastructure developed and owned by BR, bringing together the fields of Computing and Telecommunications. It can be argued that BR TOPS represented a considerable advance on the previous SP TOPS system, not only through its implementation on the more complex BR network, but also in the development of the cardless AFC systems. The degree to which TOPS was viewed as cutting edge is evidenced through the featuring of TOPS as a case-study within the Open University's Computing Courses [3].

Gourvish [32] gives a retrospective review of TOPS, pointing out that the wagon-load freight business was in decline by the 1970s, with BR pursuing trainload business which required far less emphasis on the tracking and routing of individual wagons. The argument is made by Gourvish that although the wagon load business (within which TOPS was to improve efficiencies) declined, TOPS subsequently allowed real-time management of all trains on BR and supported the development of other IT systems to manage activities as freight forecasting, passenger operations and management information systems.

There was a significant time delay between the implementation of TOPS (1970s) and the widespread adoption of telematics (1990s onward). This delay may be explained through a number of factors. Firstly developments in hardware did not make it practical to mount computing devices on vehicles and to allow their wireless connection until the 1990s. Railways, having a largely fixed infrastructure, could be managed via a centralised computing facility. The traditional management of railways with train movements being planned and then closely observed by signalling and control staff also lends itself to centralised control, indeed control centres coordinating train movements over large geographical areas had been a feature of UK railway practice since at least the mid 20th century. Such telematics systems are driven by a demand from consumers (passengers or those expecting freight deliveries) for real-time information such demand has been largely satisfied through mobile phone based applications, which are driven by large data centres which contain real-time models of the transport network. TOPS continues to provide data which is used to drive a range APIs accessible to developers [4].

At a fundamental level TOPS created a digital model of the BR system which was updated in real-time in response to train movements and customer requests. The creation of such a model and the ability to query it is a fundamental principle behind most current telematics systems. It could be argued that within that model lies the basis of what would, in contemporary terminology, be termed a Digital Twin. Let us consider a contemporary system based on telematics principles. The Edinburgh Bus Tracker system [5] is a typical example of a contemporary application of telematics, it is familiar to the author through previous work with data gathered by the system. The system provides real-time information to bus passengers (via a mobile phone app and via on-street signs) it also provides network controllers with real-time information on the location and status of vehicles. Data describing movements is collected, in this case via GPS technologies, and it is used to update a centralised model which represents the current state of the network. That model is then used to provide information to passengers and operators. It can be argued that TOPS was the first system to create a digital model of a complex transport network, updated in real-time, allowing the provision of information to management and users. Such models now underpin most systems that used to manage freight and passenger networks.

The author has not been able to examine the UK National Archives which contain material from the British Railways Board. The author understands that the TOPS related materials within the Archive comprises,reports, minutes and user-guides, duplicating the information described by Arnott [8]. Private correspondence has confirmed that some TOPS hardware is held by the National Railway Museum but this not accessible at present. Future work will include investigating both collections.

Despite TOPS having its origins in the early 1960s, TOPS continues (as of 2024) to maintain a model of the privatised

[3]Smith, Les. Personal Communication 22/22/2023

[4]Open Data Feeds (Network Rail) https://www.networkrail.co.uk/who-we-are/transparency-and-ethics/transparency/open-data-feeds/ Last accessed 19/03/2024.

[5]City of Edinburgh Council, http://www.mybustracker.co.uk/. Last accessed 19/03/2024

TABLE III
BRITISH RAIL FREIGHT AND PARCELS REVENUES (£M) TAKEN FROM [31], NOTE THAT THE FIGURES FOR 1982 ARE A CONTEMPORARY ESTIMATE.

1982 Prices	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**
Revenue	805	861	863	847	848	752	715	616
Costs	940	891	860	830	826	788	698	605
Profit/(Loss)	(135)	(30)	3	17	22	(36)	17	11

British railway network and provides data feeds for other software applications.

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Neil Urquhart is a Lecturer in Computer Science at Edinburgh Napier University. He holds a PhD in Computer Science based on the application of Evolutionary Algorithms His research interests include optimisation of logistics and transportation networks. He has written extensively on the solving of real-world problems using a range of heuristics. He also as an interest in the history of technology and transportation.

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