Safety Science 74 (2015) 93–101

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Leading indicators of operational risk on the railway: A novel use for underutilised data recordings

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ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 20 October 2014
Accepted 20 November 2014
Available online 26 December 2014

Keywords:
Data recorders
Leading indicators
Process charts
Signal detection theory

ABSTRACT

Flight Data Monitoring (FDM) is the process by which data from on-board recorders, or so-called 'black boxes', is analysed after every journey to detect subtle trends which, if allowed to continue, would lead to an accident. An opportunity has been identified to advance the state of the art in FDM processes by coupling recorder data to established Human Factors methodologies so that issues arising from the strategically important human/machine-system interface can be better understood and diagnosed. The research has also identified a significantly underused source of recorder-data within the railway industry. Taking this data, the paper demonstrates how key areas of driver performance can be quantified using a simple behavioural cluster detection method coupled to sensitivity and response bias metrics. Faced with a class of operational accident that is increasingly human-centred, an underused source of data, and methods that can join it to established human performance concepts, the potential for detecting risks in advance of an accident are significant. This paper sets out to describe and demonstrate this potential.

1. Introduction

1.1. Data recording

Data recording is the act of automatically logging information on system parameters over time. Data recording has become increasingly ubiquitous in rail transport operations. Entire national train fleets are now required to carry recorders which continuously extract data on how individual trains are being driven, at increasing rates, and across an increasing range of parameters. The outflow of data is extensive and growing yet comparatively neglected. What could it be used for? In this paper we argue it could be used to tackle the most important strategic risk issues currently faced by rail operators and authorities worldwide.

1.2. Brief history

The act of automatically recording data on system parameters over time is referred to as 'data logging' or 'data recording'. In the aviation industry the generic term data logging falls under the specific heading of Flight Data Recording, which itself comprises several individual procedures and devices. The most prominent of these is what is termed colloquially as the 'black box', which represents the combination of a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). Other systems under the heading of Flight Data Monitoring include various Aircraft Condition Monitoring Systems (ACMS), such as engine health monitoring (e.g. the Rolls Royce EHM programme) and the wide range of parameters available from modern avionics (e.g. ARINC 573) via so-called 'Quick Access Recorders' (QARs).

Data recording can trace its origins back to the allied fields of metrology, instrumentation, telemetry, predictive maintenance and condition monitoring. The Wright Brother's 1903 'Wright Flyer 1', one of the world's first powered aircraft, was equipped with "*instruments to record air velocity, engine revolutions and time while in the air*" (Ford, 2012) and herein lie the very early antecedents for the sophisticated Flight Data Recording and Monitoring that exist today. The rail sector, however, can lay claim to even earlier and more sophisticated examples of instrumentation. Stephenson's Rocket (1829), for example, had instrumentation for boiler pressure and water level, and in 1838 the Great Western Railway in the UK constructed the first 'dynamometer car', using equipment designed by Charles Babbage to integrate various readings into an accurate representation of train performance.

The use of data logging as a tool in safety science is a post-war development. It evolved amid a wider context that included a marked increase in post-war air travel, the development of new jet airliners, and accidents in which passenger aircraft 'crashed without trace' leaving investigators perplexed as to the root cause. Most notable among these were the De Havilland Comet Crashes of

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http://dx.doi.org/10.1016/j.ssci.2014.11.017
0925-7535/

1953 and 4. During the subsequent investigations it was noted that "*anything which provides a record of flight conditions, pilot reactions, etc. for the few moments preceding the crash is of inestimable value*" (Warren, 1954). The prototype 'Flight Memory Unit' (as the black box was then referred) was manufactured from early magnetic audio recording technologies and a primitive crash survivable enclosure. The device could superimpose signals from some of the aircraft's primary controls onto approximately 30 feet of metal wire at a rate of approximately eight signals per second. The device was configured so that the metal wire looped continuously, storing four hours of voice and data, continually over-writing itself.

In 1958 the UK Air Registration Board became aware of the Flight Memory Unit and due to the national importance of the jet aviation industry and the potential safety barrier that the Comet crashes represented to continued foreign sales, the concept was considered important enough to warrant further development. A British clock making company called S. Davall and Sons were able to acquire production rights and develop the first commercial 'black box', or Davall Type 1050 "Red Egg", as it was then called. Improvements now enabled readings to be captured at a rate of 24 per second, greater accuracy in the data collected from aircraft instruments and controls, and the flexibility to record voice, data or both. To do this, up to 40 miles of stainless steel wire was needed as a recording medium. An unexplained air crash in Queeensland in 1960 led to the mandatory fitment of cockpit voice recorders like these in Australia. Regulations also appeared in the United States as early as 1958, and legislation also followed in 1960 (Morcom, 1970). In Britain, changes were made to the Air Navigation Order as early as 1960 although a lengthy period of consultation and evaluation ensued, meaning that it did not become mandatory to carry a flight data recorder until 1965. With legislation imminent, however, the supply and fitment of recorders was well underway prior to this. Indeed, the first crash investigation to make substantial use of the data provided by an FDR occurred in 1965 when a BEA Vanguard fitted with a Davell Type 1050 'red egg' crashed in poor weather at London's Heathrow airport.

Early data recorders were relatively stand-alone devices. The recorder carried its own sensors and, apart from an electrical supply, operated relatively independently of the host aircraft (Campbell, 2007). Calibration proved to be a problem, with the actual state of the aircraft systems not necessarily being identical to those indicated by sensors in the recorder, or even sometimes the same as those displayed to the pilots on their cockpit displays. This 'system architecture' was to change with the advent of avionics. Avionics is the collective term given to aircraft electrical systems. The Boeing 787 and Airbus A380 represent the current state of the art and an expression of what is sometimes referred to as the 'electronic aircraft'. Here, air, mechanical and hydraulically operated systems are replaced by electrical systems, all of which reside on a communications network that can be interrogated by various aircraft systems, including flight data recorders. Rather than a stand-alone device, data recorders are now part of a comprehensive data acquisition architecture that relies on the integration of data from myriad sources via a Flight Data Acquisition Unit (FDAU), common communications protocols (ARINC 573, 717 and 767), and the use of quick access recorders as well as crash survivable 'black boxes'. Modern flight data recorders are solid state devices with the ability to continuously record over 2000 separate parameters for in excess of 30 days. The separation between a crash survivable data and voice recorder, mandated by law and used for accident investigation, and a Quick Access Recorder (QAR), not mandated but used for operational and safety purposes by airlines and regulators, occurred in the 1970s. It arose from a growing recognition that easy access to flight data, both routine and abnormal, was of value.

While the aviation sector has a long history with on-vehicle data recording devices for the purposes of safety and crash investigation, these are a much more recent innovation in the rail sector. Experience in the UK is quite typical. Here, fitment has only been mandatory since 2002 but has been the subject of discussion within the industry for many years (Uff, 2000), indeed, a Railway Group Standard (GO/OTS203) was issued in 1993 in recognition of the fact that the technology existed and was beginning to be fitted in isolated cases. The situation the industry faced was one in which costs (in terms of installation and operation) of fitting data recorders were estimated at £13,000 per unit, with savings due to investigations and repairs estimated at only £3200. In simple terms, this required investment of £75 million and would need to prevent at least two equivalent fatalities each year to show positive financial benefits (Uff, 2000, p. 177). On this basis, widespread fitment of data recorders could not be justified. Privatisation of the rail industry in 1994 and a number of coincident high profile crashes (Southall in 1997 and Ladbroke Grove in 1999) served to accelerate the adoption of data recorders. In the Southall Inquiry report it is noted that "*In my view, the cost-benefit figures produced and the conclusions that they suggest amply demonstrate the short-comings of CBA* [Cost Benefit Analysis] *as a decision-making tool [...] I believe that the general fitting of data recorders is long overdue and that this view is shared by the great majority of the industry.*" (Uff, 2000, p. 178). By 2002, Railway Group Standard GM/RT 2472 made data recorders mandatory in all new UK trains from 07 December 2003 onwards, and required that existing trains be fitted with them by 31 December 2005.

Modern trains share some conceptual similarities with aircraft in that they too make extensive use of electrical actuation (the brakes are 'electro-pneumatic' for example), rely on communications between disparate devices and systems, data buses (i.e. the Train Data Bus) and various forms of standardised communications protocol. In other words, they possess a roughly equivalent form of 'avionics' and a data bus (or 'buses') through which an on-board recorder can acquire information. There is not the same degree of conformity as in comparable avionics systems. Critical differences between the rail and aviation data acquisition architectures are, firstly, that the functions of a 'Flight Data Acquisition Unit' (FDAU) are incorporated within the On Train Data Recorder (OTDR) device itself. Likewise, so are some of the functions of a Quick Access Recorder (QAR), and as a result the data must be downloaded manually via serial cable, USB or other memory device. At the present time there is not a standard 'data frame' for OTDR data, with each device manufacturer using a proprietary version and associated analysis software. At the present time the emphasis is on individual data download and analysis for the purposes of driver training and assessment (as per the Southall Inquiry recommendations) or else incident investigation, rather than large scale data storage and industry wide analysis of 'normal' operations. Some modern rolling stock is able to wirelessly download diagnostic information for the purposes of condition monitoring but at the time of writing this is the exception rather than the rule.

1.3. Pushing the envelope

Regardless of measure, whether it takes into account exposure by distance or time, the risk to the travelling public and workforce of using and operating the railway is exceedingly low. In Europe the probability of a fatality is approximately 0.57 per billion miles (Evans, 2011), or two fatalities per 100 million person travel hours (EU, 2003). This figure arises despite the fact that exposure in time and distance have increased dramatically in some countries. In the UK, for example, between 1995 and 2012 the risk exposure by passenger distance rose by 25 billion kilometres or 58% (DfT, 2011). At the same time estimated mean fatal train accidents per