Cognitive Factors in the Paddington Rail Disaster

In 1999, a turbo train (1K20) driven from Paddington Station by an inexperienced driver (Hodder) passed signal number 63 (SN63) at a double yellow aspect, then SN87 displaying a single yellow aspect, and shortly afterwards passed signal number 109 (SN109), which showed a red light (see Appendix A for timeline). Passing both of these put 1K20 on collision course with a high speed train coming in the opposite direction, and although both drivers applied their brakes, the trains collided with a combined speed of approximately 130mph, killing 31 people including both drivers (Cullen, 2001:1, 29, 51). A number of latent and active factors were involved in causing this, however the scope of this report extends only to the major cognitive factors affecting driver Hodder. Although the factors here have been broadly divided, their effects are interrelated.

Table 1: Signal aspects and their meanings - adapted from Stanton and Walker (2011)

Colour	**Meaning**
Green	Proceed
Double Yellow	Proceed (but expect to slow down at the next signal)
Single Yellow	Proceed (but slow down to stop by the next signal)
Red	Danger (stop before this signal)

Schemata and Mental Models

Schemata are an individual's conceptual frameworks within which associated information is stored. They exist to provide expectations about how the world operates by structuring the encoding and retrieval of information, as there is too much information in the world to be understood by continually building up from direct perception and first principles (Gross, 2010). This constraint holds true for attention, perception and memory, all of which will be discussed later. A 'schema' commonly refers to a representation of a 'typical case', whereas for the purposes of this report, mental models are similar, but can be characterised by their smaller scope - an individual's internal representation of their understanding of a specific situation (or concept), particularly the spatial and functional/procedural environment in which they exist. The energy-saving shortcuts schemata provide work without mishap most of the time, but occasionally cause predictable errors.

The Automatic Warning System (AWS) was a standard system across railways in the UK that would play a tone and a visual warning approximately 200 yards ahead of each signal, and if the signal showed anything other than green, the driver had to shut off the warning within a short time or the brakes would be applied automatically (Cullen, 2001: 14). The same tone was used for multiple different aspects, eliminating any distinction between severity level, as well as a number of other pieces of information including that a speed restriction was coming up (under certain circumstances) (Stanton and Walker, 2011). This would likely have resulted in a number of schemata that associated the tone with non-danger aspects. Upon hearing the warning and seeing a triangular speed restriction sign, an inappropriate schema relating to changing speed would have been activated (Norman (1981) categorises this as a data-driven error). Hodder's immediate selection of speed notch 7 according to the On-Train Monitoring and Recording equipment (OTMR) data is consistent with this theory (Stanton and Walker, 2011). This 'correction' would have satisfied Hodder as a response to his mental model's representation of the issue in need of regulation, and so the AWS was a factor not requiring further attention.

Schemata would also have been created that gave Hodder expectations that affected other factors, and which will be shortly addressed: 11 or fewer of the times that he had passed SN109, it had a proceed aspect (Cullen, 2001: 62), and so his schema for the route would include in the form of a script (Gross, 2010) the procedural information that this was a signal through which he would always drive, and so his mental model would not flag that location on the track as one to take great care over.

Attention

Attention is defined by the philosopher James in 1890 (as quoted in Gross 2010: 198), as

> "the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalisation, concentration of consciousness are of its essence, it implies withdrawal from some things in order to deal effectively with others".

This definition and the major theories and research on attention concur that humans have a limited capacity to which they can attend, to at least the partial exclusion of other stimuli (although the paradigms differ on the mechanism for this). This is true for Treisman (1960), Treisman and Gelade (1980), Kahneman (1973) and Neisser and Becklen (1975). Indeed this was infamously demonstrated by Simons and Chabris (1999), who showed that participants were effectively blind to a gorilla beating its chest in the middle of their visual scene when attending to a different stimulus. Early models suggest that attention has a single central capacity, whereas later models suggest multiple resources based on the modality in question, with more interference caused between concurrently-used resources the more similar they are (Wickens, 1991).

There are multiple pieces of visual-modality information to which train drivers must attend, both inside and outside their cab. Driver Hodder had only recently passed his training 2 weeks prior to the incident, and had only driven at normal speed on the track in question approximately 11 times before (Cullen, 2001: 62). As a result, he was unlikely to have had enough experience to schematically internalise the task set required such that the train could be autonomously operated on the route, as described by Fitts and Posner's (1967) model. As such, he would likely have to be primarily using his attentionally expensive system 2 (as described by Kahneman, 2012) to perceive the relevant stimuli and react based on the information they provided about the system's state. If this was indeed the case, one could expect Hodder to be operating at near his attentional capacity, and unable to integrate new information into his mental model. This is one possible explanation for why, when the AWS sounded before SN87 and SN109, Hodder immediately turned it off. Comparing the predicted results from a critical path analysis (which parallelised different modalities and put matching modalities in sequence) and the OTMR timing data, Stanton and Walker (2011) concluded that Hodder was operating in a different cognitive mode for SN63 (earlier double yellow) compared to SN87 (yellow) and SN109 (red), muting the warning after only ~0.64s for the latter 2. This corroborates the theory that he could not fully attend to the warnings, and so performed as the AWS-activated schema dictated - muting the warning - to attend to other stimuli. This operation at attentional limits would also explain the absence of applying the Driver's Reminder Appliance (DRA) at SN87, as protocol and his training dictated. This later likely caused (Stanton and Walker, 2011) a 'mode error' (Norman, 1981), which will be discussed in relation to memory.

Perception

Perception is "the organisation and interpretation of incoming sensory information to form inner representations of the external world" (Gross, 2010: 225). There are 2 major theoretical processes that psychologists argue by which stimuli are perceived: 'bottom-up'/'data-driven' processing and 'top-down'/'conceptually-driven' processing (Gross, 2010). Modern models (Kintsch, 2005; Navalpakkam and Itti, 2006) suggest that both processes exist in parallel: humans partially scrutinize their expectations of reality using direct information from the world, but tend to perceive reality biased towards what they expect based on activated schemata (Kellogg, 2015).

The key points where perception was a major factor in the Paddington Rail disaster was when 1K20 passed the signals in general, and SN109 showing a red aspect in particular. Cullen (2001: 51) concludes that Hodder believed that SN109 was showing a proceed aspect, which suggests that if he attended to it at all, he perceived it incorrectly. There are a number of reasons why Hodder may have incorrectly perceived the aspect, however these may be focussed based on the knowledge that SN109 was a signal that had been passed with a danger aspect (SPAD) multiple (8) times before (Cullen, 2001: 251-259).

Many of the drivers previously responsible for a SPAD stated that they expected a proceed aspect and so did not respond until later than they should have. Both this testimony and the aforementioned schema/mental model suggest that Hodder was operating with a perceptual set that influenced his actions. One driver mentioned that they perceived a signal over a different track to be the one that pertained to them, matching criticism that there were 6 signals, compared to a normal total of 2 or 3 (Cullen, 2001: 109). This would have made the visual search harder, and the perceptual set suggests a proceed aspect on a nearby signal would not have been questioned. A bridge before gantry 8 meant SN109 was the last of the signals in the gantry to become visible, meaning Hodder may already have seen a nearby signal and internalised its aspect. The perceptual task was made more challenging by the fact that SN109 had an unusual layout, with the lights arranged in a reverse 'L' shape, meaning that a red light in the bottom left may not match the predisposed pattern of a red directly underneath the other lights to be conspicuous enough to an already attentionally-depleted driver.

Working Memory

Memory in general refers to the storage, encoding and retrieval of information. Traditional models focus on either the structural components of memory, as in the Multi-Store Model (MSM) (Atkinson and Shiffrin, 1968), or the factors and processes involved in each stage, as with the Levels of Processing theory (Craik and Lockhart, 1972). Working memory is conceptually similar to the short-term memory store (as described in the MSM) in its short timeframe and the scale at which it can hold information. However, rather than just having one theoretical structure, working memory involves multiple interacting subsystems that cooperate to inform behaviour (Cowan, 2008). The basic working memory model consists of three components, the visuospatial sketchpad, the episodic buffer and the phonological loop, all of which are controlled by a central executive, which controls where attention is focussed and how subsystems are used (Baddeley and Hitch, 1974; Baddeley, 1996, 2000).

Even though Hodder had not perceived the red aspect at SN109, one might expect him to remember the single yellow from SN87 or double yellow from SN63 and to stop before the next signal, however this would underestimate the fragility of information held in working memory. The DRA was intended to help here, but as it was not activated, Hodder was left to rely on his internal memory, resulting in the mode error that enabled him to intentionally accelerate at SN109. The lack of experience on this track would mean that his schema of it was incomplete, and so would still have to keep a number of pieces of information in his working memory rather than retrieving them from a long term store as needed (Baddeley, 2000), further increasing the difficulty of visual attention (de Fockert et al., 2001). Visual information is only held briefly, and must enter the phonological loop to be maintained for longer periods (Sperling, 1963). This is one stage where Hodder's memory may have failed, however even if transferred into the phonological loop, Rose, Craik and Buchsbaum (2015) demonstrated the importance of a semantic level of processing for maintaining information in the working memory; consider the following possible loops: "that light was red", "the brake needs to be applied soon to stop before the next signal". The latter would have been better remembered *and* given cues as to the proceeding actions to take.

Miller (1956) showed that only between 5 and 9 chunks of information can be kept in working memory, so even if the high level of processing occurred, Hodder would only have to attempt to remember a small amount more information before the memory of the requirement to stop was displaced, as described by Gross (2010). As discussed, his incomplete schema would mean more information needed to be held in working memory. There would be many things to remember, particularly signs and signals (Stanton and Walker, 2011) as well as possible information to tell the train passengers, as with a previous SPAD driver (Cullen, 2001: 257), or simply other, task-irrelevant pieces of information. This forgetting would be described by Norman (1981) as a loss-of-activation error.

Conclusion

The proposed combination of major cognitive factors is as follows. Hodder's partially formed schemata contained associations that contributed to misperception of the aspect at SN109, the visual search for which was made more difficult by the loaded attentional and working memory systems. A loss-of-activation error of information regarding previous signals displaced from working memory resulted in a mode error that enabled intentional acceleration at SN109. Insufficient attentional capacity led to not applying the DRA memory prompt, and combined with an inappropriate schema led to the data-driven error of associating the AWS with a speed restriction rather than the red aspect. These factors aligned as in Reason's (1990) Swiss cheese model: no factor alone would have caused the crash, indeed it was only by the existence and interaction of all of the factors detailed above that resulted in this disaster.

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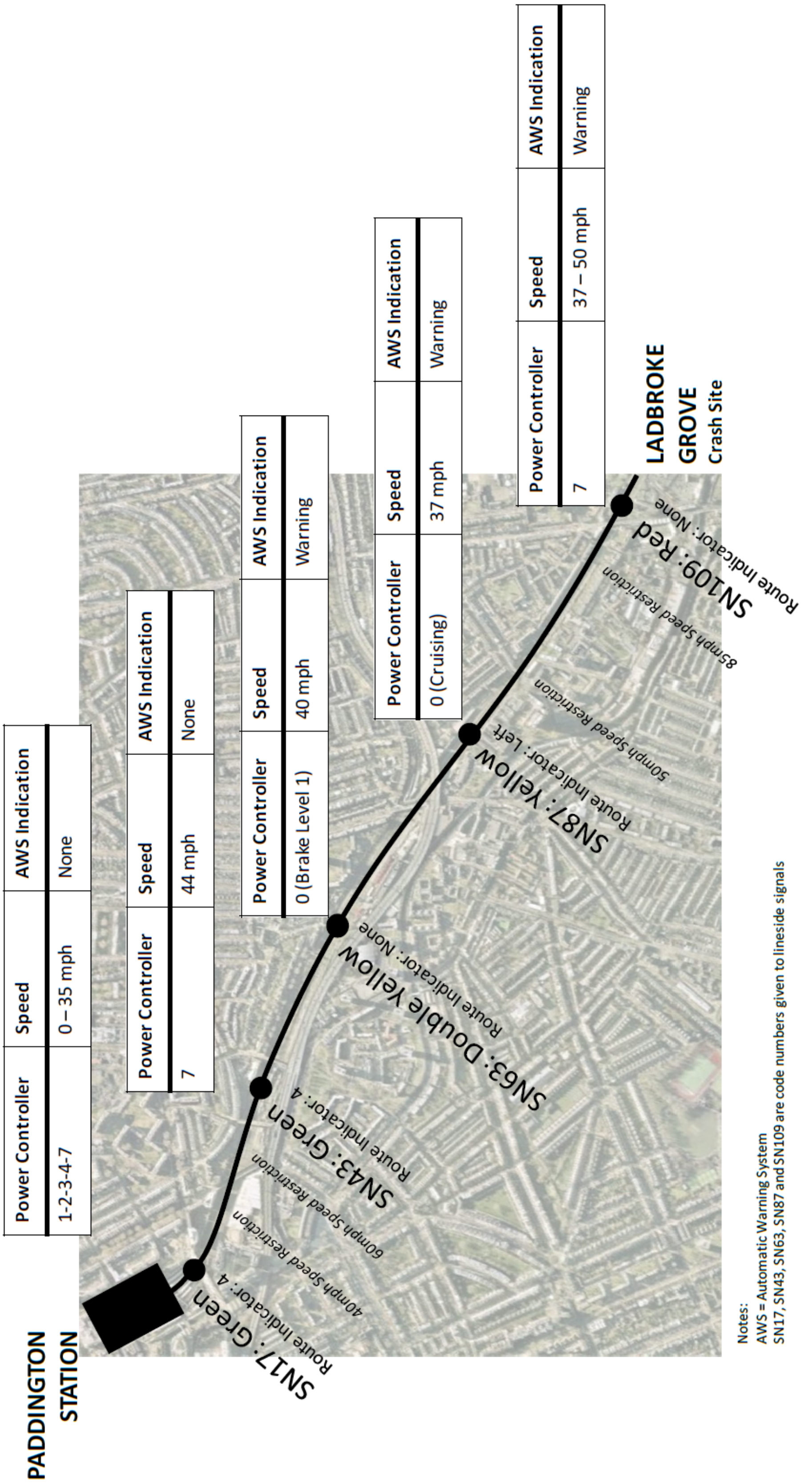
Appendix A: Event timeline



From Stanton and Walker (2011)