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A systemic analysis of the Edge Hill railway accident

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ABSTRACT

The Edge Hill railway accident occurred on Sunday 9 May 1999 in Liverpool, England. An Engineers' scrap train struck a plant quality supervisor. This paper presents the results of a systemic analysis of the accident. The methodology has been to compare the features of the Edge Hill accident with the structural organization (i.e. systems 1–5) of a Systemic Safety Management System (SSMS) model, which has been constructed by employing the concepts of systems. A number of systemic failures have come to light. The findings are related to causal factors of failure of systems 1–5 as well as missing channels of communication amongst those involved in the maintenance work. It is hoped that this systemic analysis will help to identify 'learning points', which are relevant for preventing accidents; especially accidents involving track-side workers.

1. Introduction

The British railway industry was privatized in 1994 and, when completed, the former British Rail (BR) organization had become split into more than 100 organizations; either sold or franchised. A consequence of this was the separation of the management of 'track' from that of 'train'. However, the fragmentation of the management structure was not only applied to train operations. All the physical work involved in maintaining, renewing and enhancing the rail infrastructure (i.e. track, bridges, tunnels, signalling, electrification, etc.) was transferred to contractors. As a result thousands of experienced engineers, operators and supervisors departed from the industry. Track-side workers are exposed daily to the highest risk of fatality during the maintenance and renewal of the railway infrastructure. Often, this work is carried out close to or on the running track known as 'the line'. Some of the work can be done by machine but often people also have to be involved and this can create considerable risk of track-side workers being struck by trains. An example of such risks becoming realized was the case of the fatal accident that occurred at Edge Hill, Liverpool, England in 1999 where a plant quality supervisor (PQS) was struck by a scrap train (Railtrack, 1999).

The UK framework for track safety requires, by law, railway employers to be responsible for ensuring that risks to employees are as low as reasonably practicable (ALARP) (HSE, 2001a,b). The legislation relevant to this particular topic includes: The Railways Act 1993; Railway (Safety Case) Regulations 2000 (HSE, 2001a,b); Health and Safety at Work, etc., Act 1974; and Railways (Safety Critical Work) Regulations 1994 (HSE, 2004). In addition to these, there are a set of technical standards and operating and management procedures that, along with the Railway Safety Cases, provide the industry framework for 'safe' operation. The Group Standards are divided into two categories: {a} the Rule Book, Track Safety Handbook and Safety Codes, and {b} other mandatory and non-mandatory Standards. The Rule Book, Track Safety Handbook and Safety Codes contain detailed requirements relating to track safety and are aimed at track workers at all levels, including the Controller of Site Safety (COSS) and Person in Charge of Possession (PICOP). For instance, the Rule Book Section T(iii) "'Possession of the line for engineering work'. Applies when engineering work takes place on running line and requires complete stoppage of normal train movements but may require the movement of engineering trains in connection with the work. It includes the duties of and interactions between the PICOP, ES, signallers, drivers and shunters arranging, granting, during and giving up a possession" (Railway Group Standards, 1999; RSSB, 2003). Other Standards relevant to track safety are the RIMINI (risks minimisation) and RT/LS/S/019. The RIMINI (RSSB, 2004) is a mandatory requirement for all work

Abbreviations: HSE, health and safety executive; LSMU, local safety management unit; MORT, Management Oversight and Risk Trees; PICOP, Person In Charge of the Possession; PQS, plant quality supervisor; PRISMA, Prevention and Recovery Information System for Monitoring and Analysis; PWSM, Permanent Way Section Manager; R&D, research and development; RIMINI, risk minimisation; RSSB, Rail Safety and Standards Board; SPAD, signal passed at danger; SSMS, Systemic Safety Management System; STAMP, Systems Theoretic Accident Modelling and Process; TSMU, total safety management unit; UFL, Up Fast line; WBA, Why-Because Analysis; WON, Weekly Operating Notice.

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done by groups under to control of a COSS on the rail infrastructure. The RT/LS/S/019 (Railtrack, 2002), on the other hand, is a Railtrack company standard, 'Protection of People Working On or Near the Line' and was issued in April 2002. The introduction of the new rules together with 'Red and Green Zone working' were intended to help to increasing the 'safety' of trackside work.

1.1. Related work

Accidents and incidents are investigated in order to help to identify the causes of their occurrence and to determine the actions that must be taken to prevent recurrence. Accident investigators need to identify and document not only the event themselves, but also the relevant conditions affecting each event in the accident sequence. A number of methods for root cause analysis were developed during the 1970s and 1980s by the US Department of Energy and the national Transportation Safety Board (Johnson, 2003; Johnson and Holloway, 2003). Johnson has classified these techniques into "elicitation approaches", "incident reconstruction" and "argumentation" techniques. The author argues that "elicitation" techniques; for example, Barrier and Change Analysis, may assist in the elicitation of information after an accident because they "encourage investigators to determine both what did happen and what should have happened". "Incident reconstruction" analysis techniques, on the other hand, can be used to map out the sequence of events leading to an accident. Examples of techniques that support incident reconstruction are: Timelines, Accident Fault Trees, Failure Event Trees, etc. Many of these techniques use a second stage of analysis based on counterfactual reasoning to distinguish root causes from contributory factors.

In general, it may be argued that most reconstruction methods can be applied to analyse a range of accidents from different industries. However, it is not clear whether different analysts will reach the same conclusions about the same accident. Flow Chart methods; such as, MORT (Management Oversight and Risk Trees) (Johnson, 1973) and PRISMA (Prevention and Recovery Information System for Monitoring and Analysis) (Van der Schaaf, 1996), are intended to help to encourage consistency by guiding analysts to reach a limited number of conclusions about the causes of an accident. Flow charts and reconstruction techniques make minimal assumptions about the nature of accidents or incidents. In contrast, 'accident models' are intended to provide guidance about the manner in which accidents are caused. For instance, the "Tripod-Delta" and "Review" methods (Reason, 1997) are intended to help the analyst to trace the way in which barriers fail to protect a target from a hazard. In addition, the preconditions for the failure of any barrier must be tied back to a number of General Failure Types. Similarly, Leveson et al. (2003) proposed a method called the "Systems Theoretic Accident Modelling and Process" (STAMP) and it models accidents using control theory. Leveson argues that accidents are conceived as resulting from inadequate control of safety related constrains on the design, development and operations of the system (Leveson, 2004). Other researchers, such as Ladkin and Loer (1998) have developed a method called "Why-Because Analysis" (WBA) that is intended to address the structure of arguments that are made about the causes of accidents.

This paper presents the results of a systemic analysis of the Edge Hill railway accident. The methodology has been to compare the features of the Edge Hill accident with only one characteristic of the Systemic Safety Management System (SSMS) model; that is, the structural organization which consists of five highly inter-related subsystems (systems 1–5). The main source of information was the report produced after the inquiry into this accident by Railtrack (1999). A number of systemic failures have come to light. The findings are related to causal factors of failure of systems 1–5 as well as missing channels of communication amongst those involved in the maintenance work.

The paper is organized as follows: a description of the Edge Hill railway accident is presented in Section 2. A brief description of the structural organization of the SSMS model is presented in Section 3. The analysis of the accident is given in Section 4 and, finally, Section 5 presents some conclusions and future work.

2. The Edge-Hill railway accident

On Sunday 9 May 1999 a plant quality supervisor employed by 'Jarvis Rail', was killed by an Engineers' scrap train ('7L42'). The train left from a 'T (iii) possession' on the UP Fast line at Edge Hill East Junction, Liverpool, England. The train was operated by English Welsh and Scottish Railway (EWS). The location of the accident was at 192 miles on the Up Fast line of the four-track railway between Edge Hill East Junction and Liverpool Lime Street Station. The maximum permitted speed was 30 mph in normal operations.

A 'T (iii) possession' of the Down and Up Fast lines between Edge Hill East Junction and Liverpool Lime Street was programmed from 0130 to 0745 on Sunday 9 May 1999, in the Weekly Operating Notice (WON). The 'Track-work' to be carried out by Jarvis Rail included the following:

{a} 'S&C' tamping on Down and Up Fast lines at Edge Hill East Junction.
{b} An 'Engineer's scrap train', on the Up Fast line, to pick up rubbish between Tunnel Road tunnel and Crown Street tunnel.
{c} The movement of 'S&C' materials to a site at Lime Street on the Down Fast Line.

'Tamping operations' may be described, in its simple form, as a process of alignment of rails by the use of the so-called Tamping machine. A Tamper machine is thought to consist of a number of vibrating 'rods' which when dug into the ballast material cause it to pack more firmly under the track. 'S' refers to 'switch'; that is, a pair of linked rails that can moved laterally in order to allow a train to pass from one line to the other. The whole set of rails making up such a junction is being referred to as 'points' or 'switch'. 'C' stands for 'crossing'; that is, one rail crossing another on the same level.

A pre-planning meeting took place on Thursday 6 May 1999 which was chaired by Mr R. McStein, 'PWSM' (a Permanent Way Section Manager). The meeting was attended by the following persons: Mr Russel, the 'PICOP' (Person In Charge of the Possession) and two Engineering Supervisors (ES), Mr P. Goulding and Mr P. Evans. Mr Goulding was assigned to be ES for item {b} and Mr Evans for item {c}. On the other hand, it is said that (Railtrack, 1999) Mr P. White, the PQS or Tamping Supervisor, who was to be ES for item {a}, had been invited but he did not attend the meeting, although he was present in his office in the same building where the meeting took place. The subject of the meeting was those aspects concerned with protection arrangements, location of work sites, the working of the 'Engineer's scrap train', the position of the Marker Boards for items {b} and {c} and the 'Points' to be tamped. Although the PWSM ordered 10 sets of Marker Boards for use in the possession, the position of Marker Boards for item {a} was not discussed. In addition to the above, it was decided by the PWSM that mobile telephones were to be used as a means of communication between the PICOP and the ES, during the possession. Those who were present at the meeting exchanged their mobile telephone numbers but they did not know Mr White's telephone number.

The sequence of events of the fatal accident is thought to be (Railtrack, 1999):

00:50	PICOP, Mr Russell, took 'possession' of the Down Fast Line (DFL) (Edge Hill to Lime Street) to enable ES Mr Evans to start work.
01:18	PICOP extended possession of the DFL beyond Edge Hill East Junction at signal LE43.
01:40	PICOP took possession of Up Fast line (UFL) from Lime Street to Edge Hill East Junction.
01:40–02:00	The signaller had the PICOP's permission to allow the Engineer's scrap train to enter the possession on the UFL. Mr Goulding had discussed the possibility of 'propelling' the scrap train out of the possession after loading, rather than 'running round' at Lime Street as planned. He advised this change of plan to the PICOP.
02:00–02:15	Mr White, ES for 'Tamping operations', briefed the machine crew about the worksite and possession arrangements. There were no Marker Boards to protect the worksite in which the Tamper machine and the track-workers were working.
03:30	Mr Evans, ES for 'movement of S&C materials' completed his work at Lime Street and, with the PICOP's knowledge, transferred his 'workers' to Edge Hill Station to move rails on the DFL.
03:50–04:05	The Tamper machine completed work on the UFL, and then transferred to the DFL.
04:00	Mr Goulding informed the PICOP that loading was completed, and that he had moved the scrap train out of the worksite into the platform at Edge Hill Station.
04:20	The PICOP informed the Edge Hill signaller that Mr Goulding would telephone him when the scrap train was ready to depart from the UFL to 'Tuebrook sidings'.
04:30	Mr Goulding advised the Edge Hill signaller that the train was ready to depart.
04:35	The Edge Hill signaller set the route for the train. By this time the Tamper machine was in full operational mode on the DFL with its lights on. Mr White had been struck and severely injured
04:55	Emergency services arrived but Mr White was pronounced dead.

3. A SSMS model

The SSMS model is intended to maintain risk within an acceptable range in an organization's operations. The model is proposed as a sufficient structure for an effective safety management system. It has a fundamentally *preventive* potentiality in that if all the sub-systems and connections are present and working effectively, the probability of a failure should be less than otherwise. Table 1 lists the fundamental characteristics of the model.

Table 1
Fundamental characteristics of the SSMS model

1. A structural organization which consists of a 'basic unit' in which it is necessary to achieve five functions associated with systems 1–5 (see Fig. 1).
   (a) System 1: safety-policy implementation
   (b) System 2: safety-co-ordination
   (c) System 3: safety-functional
   (d) System 3*: safety-audit
   (e) System 4: safety-development
   (f) System 4*: safety-confidential reporting system
   (g) System 5: safety-policy
   (h) 'Hot-line'

Note: whenever a line appears in Fig. 1 representing the SSMS model, it represents a channel of communication, except for the lines that connect the balancing loop that connects systems 4 and 3.

2. The SSMS and its 'Environment'.
3. A recursive structure (i.e. 'layered') and 'relative autonomy'.
4. The concept of MRA (Maximum Risk Acceptable), *Viability* and acceptable range of risk.
5. Four principles of organization.
6. 'Paradigms' are intended to act as 'templates' giving essential features for effective communication, control and 'human factors'.

A full account of the above characteristics of the model has been discussed by (Santos-Reyes and Beard, 2002, 2006, 2008) where many references are given. A brief description of the structural organization (i.e. systems 1–5) will be given in the subsequent paragraphs.

3.1. *Structural organization of the SSMS model*

The SSMS model has a 'basic unit' in which it is necessary to achieve five functions associated with systems 1–5. Systems 2–5 facilitate the function of system 1, as well as ensuring the continuous adaptation of an organization as a whole. The five functions are the following: formulation of the safety-policy, safety-development, safety-functional, safety-co-ordination, and safety-policy implementation. Referring to Fig. 1.

3.1.1. *System 1: safety-policy implementation*

System 1 may be regarded as the core of the SSMS model; that is, it is where the business process of an organization takes place and therefore, it is where risks are created. System 1 implements safety policies in the organization's operations. For the purpose of the analysis of this particular accident system 1 has been decomposed on a basis of functions and the following sub-systems have been identified: {a} system 1-A ('Tamping operations'); system 1-B ('scrap trains operations'); and {c} system 1-C ('movement of S&C materials operations'). A full account of these subsystems is given in Section 4.1.

3.1.2. *System 2: safety-co-ordination*

The function of system 2 is to co-ordinate the activities of the operations of system 1. System 2, along with system 1, implements the safety plans received from system 3. It informs system 3 about routine information on the performance of the operations of system 1. To achieve the plans of system 3 and the needs of system 1, system 2 gathers and manages the safety information of system 1's operations. An example of co-ordination activity could be the solving of any conflict that may arise amongst the three subsystems identified in the previous section.

3.1.3. *System 3: safety-functional*

System 3 is directly responsible for maintaining risk within an acceptable range in system 1, and ensures that system 1 implements the organization's safety policy. It achieves its function on a day-to-day basis according to the safety plans received from system 4. System 3 requests from systems 1, 2, and 3* information about the safety performance of system 1 to formulate its safety plans and to communicate future needs to system 4. It is also responsible for allocating the necessary resources to system 1 to accomplish the organization's safety plans.

3.1.4. *System 3*: safety-audit*

System 3* is part of system 3 and its function is to conduct audits sporadically into the operations of system 1. System 3* intervenes in the operations of system 1 according to the safety plans received from system 3. System 3 needs to ensure that the reports received from system 1 reflect not only the current status of the operations of system 1, but are also aligned with the overall objectives of the organization. The audit activities should be sporadic (i.e. unannounced) and they should be implemented under common agreement between system 3* and system 1. The revision of the adequacy and the functioning of the engineering services and fixed installations of the railways (e.g. track, signalling, structures, telecommunications, buildings, stations and depots) are examples of the action of system 3*.

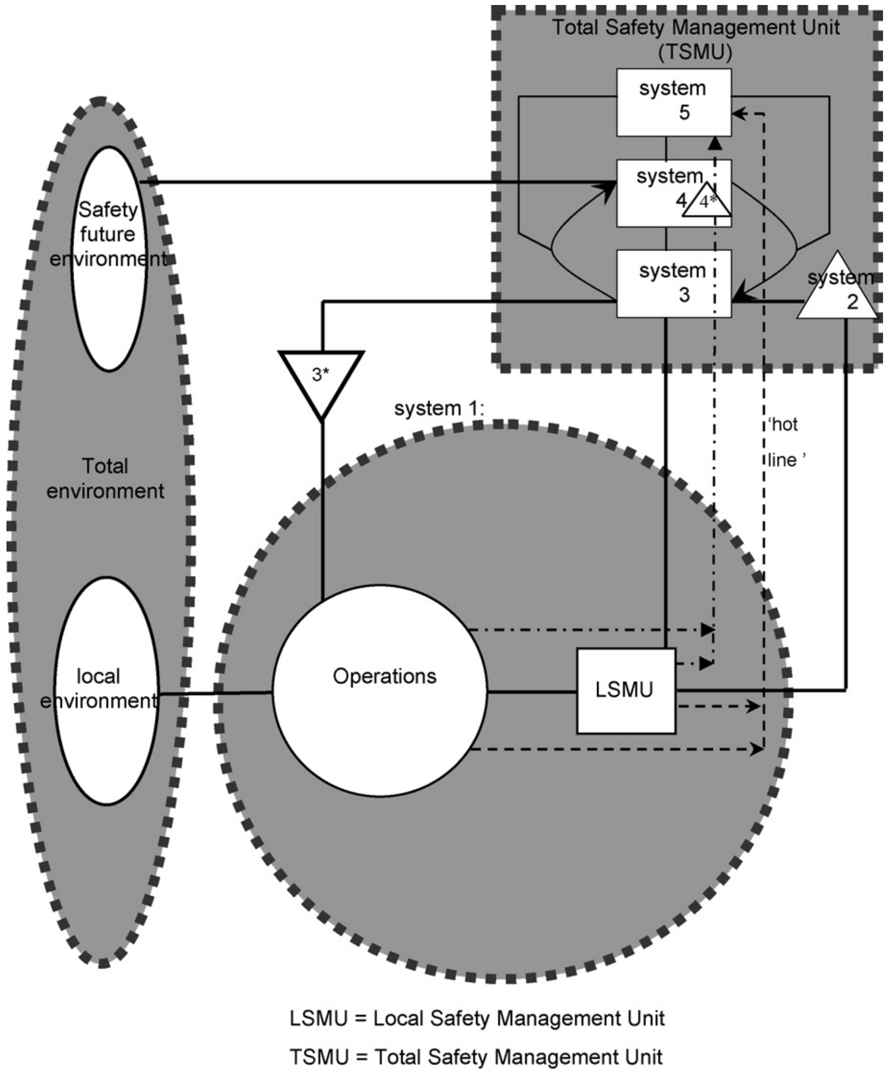

Fig. 1. A structural organization of a SSMS model.

3.1.5. System 4: safety-development

System 4 is concerned with safety research and development (R&D) for the continual adaptation of the railway system as a whole. By considering strengths, weaknesses, threats and opportunities, system 4 can suggest changes to the organization's safety policies. This function may be regarded as a part of effective safety planning. Firstly, system 4 deals with the safety policy received from system 5. Secondly, it senses all relevant threats and opportunities from the total physical and socio-economic environment of the organization; including the railway 'safety future environment'. Thirdly, system 4 deals with all relevant needs of system 1's performance and its potential future. Finally, it deals with the confidential or special information communicated by system 4*.

3.1.6. System 4: safety-confidential reporting system*

System 4* is part of system 4 and is concerned with confidential reports or causes of concern from any employee, about any aspects, some of which may require the direct and immediate intervention of system 5.

3.1.7. System 5: safety-policy

System 5 is responsible for deliberating safety policies and for making normative decisions. According to alternative safety plans received from system 4, system 5 considers and chooses feasible alternatives, which aim to maintain the risk within an acceptable range throughout the life cycle of the total railway operations. It also monitors the interaction of systems 3 and 4, as represented by the lines that show the loop between systems 3 and 4 as shown in Fig. 1. An example of system 5's policies is to address the prevention of train accidents. These policies should also promote a good 'safety culture' throughout the organization and amongst the organizations involved in the operation, maintenance, renewal and the enhancement of the rail network.

3.1.8. The SSMS and its 'Environment'

The organizational structure of the SSMS is shown as interacting in a defined way with its 'environment' through system 1's operations, and through system 4, as illustrated in Fig. 1. 'Environment' may be understood as being those circumstances to which the SSMS response is necessary. 'Environment' lies outside the

SSMS but interacts with it; it is the source of circumstances that threaten the system; for example, economic and political drivers, national and local cultures, etc. System 4 deals with both 'total environment' represented as an elliptical broken line symbol and the 'future environment' embedded into the 'total environment' as shown in Fig. 1. The safety 'future environment' is concerned with threats and opportunities for the future development of safety. See Santos-Reyes and Beard (2008) for further details about this.

Fig. 1 shows a dashed line directly from system 1 to 5, representing a direct communication or 'hot-line' for use in exceptional circumstances; e.g. during an emergency. Also shown in Fig. 1 is a line with an arrow from system 1 to 4* and system 5, representing a safety confidential reporting system. Both channels, the 'hot-line' and the confidential reporting system, represent 'initially' one-way communication channels but they may become two way communication channels between systems 1 and 5 and 1 and 4*,

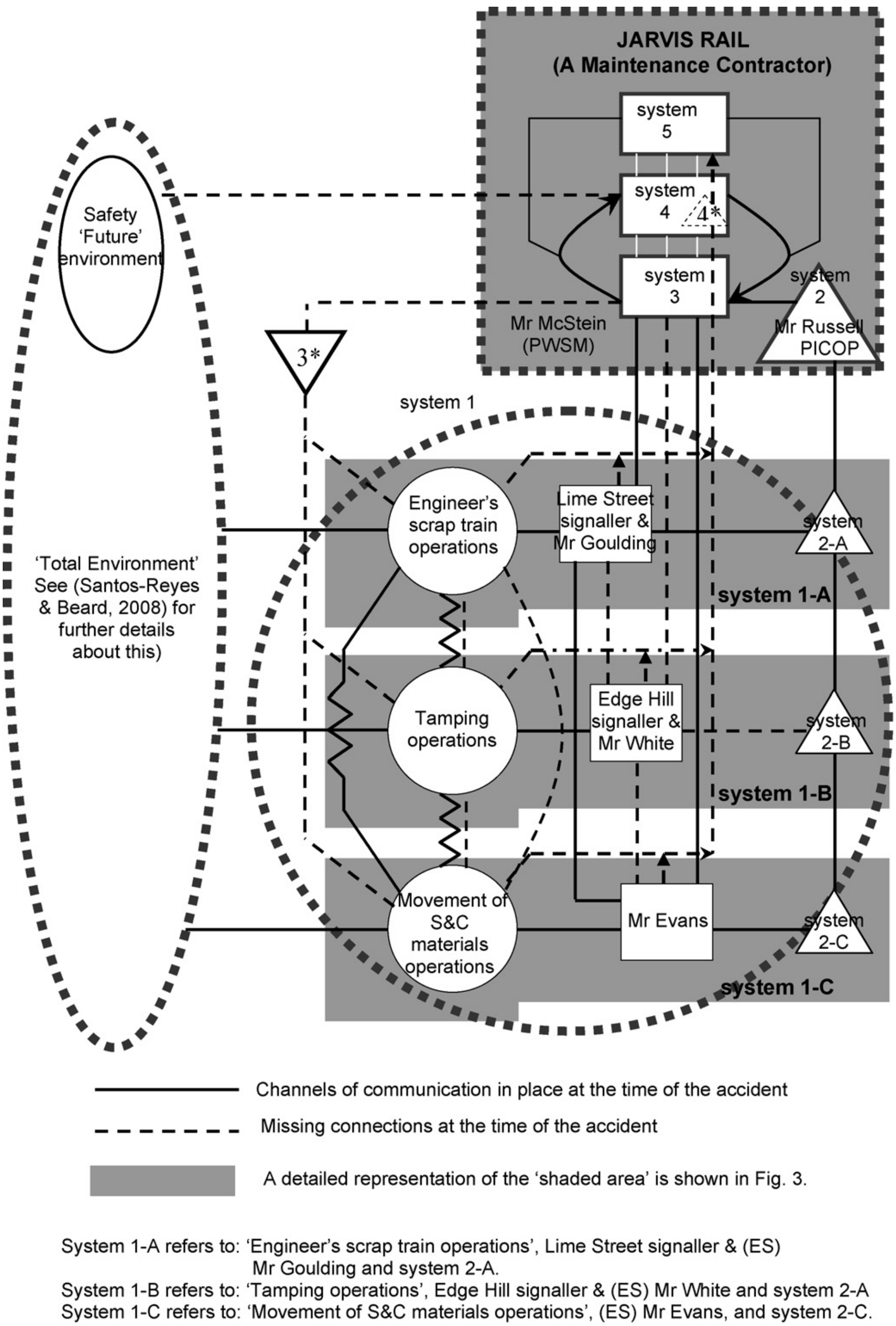

Fig. 2. Structural organization mapping of the SSMS model with the failed system.

respectively. Whenever a line appears in Fig. 1 representing the SSMS model, it represents a channel of communication, except for the lines that connect the balancing loop that connects systems 4 and 3.

4. The analysis

The methodology used for the analysis has been to compare the features of the Edge-Hill accident with the structural organization (i.e. systems 1–5) of the SSMS model. That is, the model has been used as a 'template' and 'laid on' to the features of the accident. Fig. 2 shows the discrepancies that have been thrown up and these are presented in the next section.

4.1. System 1: safety-policy implementation

The mapping in Fig. 2 shows discrepancies in relation to the connections amongst the operations involved in the 'possession management' at the time of the accident and these are indicated by the dashed lines (for clarity the 'hot-line' has been omitted from this diagram. There was not a hot-line at the time of the accident). Table 2 presents the 'operational' mappings and Table 3 summarizes the 'managerial' mappings.

The lack of the connections summarized in Table 2 stemmed from the fact that the 'management unit of system 1-B' (Mr White) did not attend a pre-planning meeting. In the meeting it was agreed that mobile telephones were to be used for communications within the possession.

In order to understand further the effects of the above it was necessary to analyse in detail the function associated with system 2. A detailed representation of the channels of the shaded area of system 1 of Fig. 2 is shown in Fig. 3. The next section presents the results of the comparison process.

4.2. System 2: safety co-ordination

The function of system 2 is to co-ordinate the activities of the operations of systems 1-A, 1-B and 1-C in Fig. 2. To achieve the plans of system 3 and the needs of system 1, system 2 gathers and manages the safety information of system 1's operations.

In a relatively 'well' co-ordinated system the information flows might be according to the arrangement shown in Fig. 3. In general, the arrangement indicates that if a deviation occurs from the accepted criteria (e.g. a SPAD) or any change from the agreed plans amongst the sub-systems that form part of system 1; then, the functions of system 2 are the following: first, communicate about it to other sub-systems within system 1 and, second, to devise measures to be implemented within its operations (in the following an 'action' such as '2A', must be distinguished from the system 2-A).

Tables 3–5 show the deficiencies of the actions associated with the Engineering Supervisors who performed the functions associated with system 2. More specifically Tables 3 and 5 show deficiencies in the actions of co-ordination associated with the Engineering Supervisors who performed the activities associated with systems 1-A and 1-C in Figs. 2 and 3.

4.2.1. Case 1: change of plan in system 1-A (see action point '2' in Table 3 and Fig. 3)

First, the change of plan of system 1-A was that:

Mr Goulding considered the "possibility of propelling the scrap train out of the possession rather than 'running round' at Lime Street" (Railtrack, 1999, p. 16) as originally planned.

Second, the function of system 2-A is to communicate about the 'change' simultaneously to:

Table 2
Summary of the 'managerial' mappings (see Fig. 2)

System 1 (1-A, 1-B and 1-C), systems 2 and system 3	System 1 (1-A, 1-B and 1-C), system 2 and system 3						
	System 1-A ('square box' on Fig. 2)		System 1-B ('square box' on Fig. 2)		System 1-C ('square box' on Fig. 2)	System 2 Mr Russel (PICOP)	System 3 Mr McStein (PWSM)
	Lime Street signaller	Mr Goulding (ES)	Edge Hill signaller	Mr White (ES)	Mr Evans (ES)		
Lime Street signaller		√	√	Need more information	Need more information	√	Need more information
Mr Goulding (ES)	√		√	Missing channel	√	√	√
Edge Hill signaller	√	√		Missing channel	Need more information		Need more information
Mr White (ES)	Need more information	Missing channel	One way channel (i.e. from Mr White to signaller)		Missing channel	One way channel (i.e. from Mr White to PICOP)	Missing channel
Mr Evans (ES)	Need more information	√	√	Missing channel		√	√
System 2 Mr Russel (PICOP)	√	√	√	Missing channel	√		√
System 3 Mr McStein (PWSM)	Need more information	√	Need more information	Missing channel	√	√	

Table 3
System 2-A; 'Engineer's scrap train operations' (see Figs. 2 and 3)

Action point	Required by the SSMS model System 2-A description	'Possession Management' at the time of the accident Lime Street signaller and Mr Goulding performed the functions associated with system 2-A
1	Relevant information to system 2-A related to the Engineer's scrap train operations.	Engineer's scrap train '7L42' was monitored by the Lime Street signaler. Channel of communication was in place in the form of supervision by Mr Goulding.
2	Interpretation of the information being received from the operations; any change of plans about the scrap train operations (for example, change of the train's route) need to be communicated to actions '3' and '2A' within system 1-A (see Fig. 3).	Mr Goulding considered the possibility of propelling the scrap train out of the possession after loading, rather than 'running round' at Lime Street as originally planned.
2A	(a) Receives information from system 2 (e.g. PICOP)	(a) PICOP (Mr Russell) gave permission to the signaller to allow Engineer's scrap train to enter possession on the Up Fast line.
	(b) Receives information from systems 2-B and 2-C through actions '7A' and '12A' respectively.	(b) Mr Goulding was not advised about the change of plans of Mr Evans (system 2-C). There was no channel of communication between Mr Evans and Mr White (system 2-B).
	(c) Communicates about any change from a pre-planned work activity within system 1-A (e.g. a change of train's route) to: •System 2-B •System 2-C	(c) Mr Goulding did not communicate about the change of the train's route to: •Mr White and Edge Hill signaller (who performed the action associated with system 2-B). •Mr Evans (who performed the activities associated with system 2-C).
3	Receives information about the new train's route from action '2' and assesses its consequences.	Lime Street signaller was confirmed by PICOP for the scrap train to move into the Edge Hill platform and then proceed out of the possession.
4	Planning and taking measures in order to respond appropriately to the 'new change' (rules and regulations applicable to the situation).	Lime Street signaller (the signaller performed the activity associated with action '9'; see Fig. 3) agreed to set the route from signal 'LE44' via signal 'LE36'.
4A	Communicates about the 'change' to system 2 (see Fig. 3).	Mr Goulding communicated about the train's change of route to the PICOP through action '4A' (see Fig. 3).
5	Implementation of 'measures' to prevent the 'change' of plans leading to a dangerous incident.	It did not happen.

Table 4
System 2-B; 'Tamping operations' see Figs. 2 and 3

Action point	Required by the SSMS model System 2-B description	'Possession Management' at the time of the accident Edge Hill signaller and Mr White performed the functions associated with system 2-B
6	Relevant information to system 2-B related to the 'Tamping operations'	The Edge Hill signaller monitored the 'Tamper machine'. This channel of communication was in place in the form of supervision by Mr White. However, unclear how effective it was.
7	Interpretation of the information being received from the operations (e.g. a change of Tamper machine's route or any change from a pre-planned work activity within system 1-B) that needs to be communicated to actions '8' and '7A' as shown in Fig. 3.	Deficiencies of the actions taken in relation to this activity. For example, at 0350 Mr White decided that the Tamper machine had to be transferred from the Up line to continue work on the Down Fast line but without receiving authority of the PICOP.
7A	(a) Receives information from system 2.	(a) Mr White (who performed the activities associated with system 2) did not receive any information from the PICOP in relation, for example, of the change of plans of Mr Goulding (system 1-A).
	(b) Receives information from systems 1-A and 1-C through actions '2A' and '12A', respectively.	(b) Mr White did not receive any information concerning the change of plans of Mr Goulding (system 1-A) and Mr Evans (system 1-C).
	(c) Communicates about any change from a pre-planned work activity within system 1-B to: •System 2-A •System 2-C	(c) This activity was not performed effectively; for example, Mr White did not communicate about the Tamper machineĭs operations on the Down Fast line to: • Mr Goulding (who performed part of the activities associated with system 2-A). • Mr Evans (who performed the activities associated with system 2-C).
8	Receives information about the new change from action '7' and assesses its consequences.	Mr White arranged with the signaller about the new plan of the transfer of the Tamper machine to continue work on the Down Fast line. However, he did not assess the consequences of the changes of plans of Mr Goulding and Mr Evans.
9	Planning and taking measures in order to respond appropriately to the 'new change' (rules and regulations applicable to the situation)	The signaller performed the function of action '9' of Fig. 3. Deficiencies of Mr White's actions; for example, he did not arrange the erection of Mark Boards at either side of the Tamping operations.
9A	Communicates about the 'new change' to system 2 (see Fig. 3).	It did not happen.
10	Implementation of 'measures' to prevent the 'new change' leading to a dangerous incident.	It did not happen.

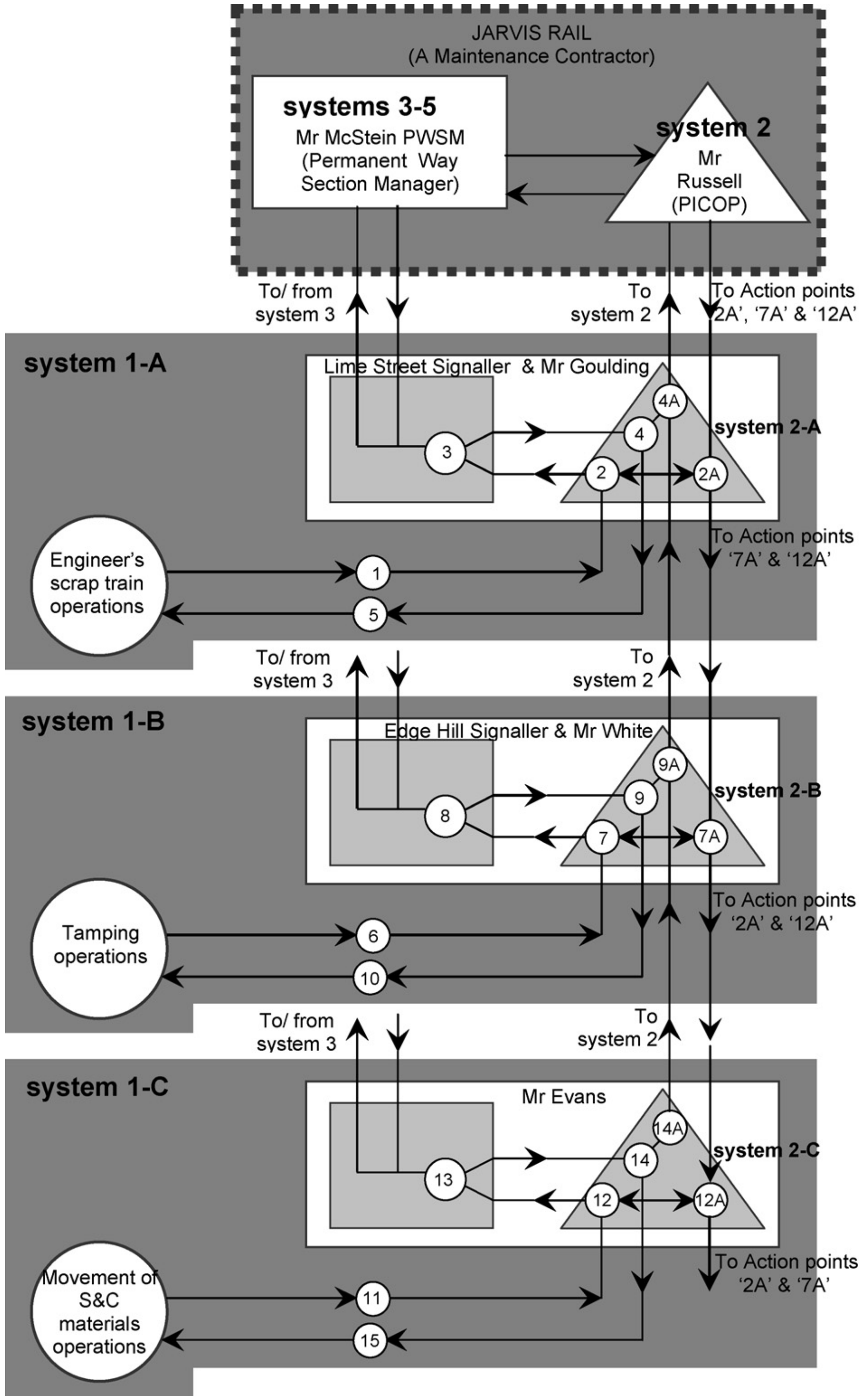

Fig. 3. System 2: safety coordination of a SSMS model.

{a} System 2-B. Once the information has been received; it has to assess consequences and implement measures within its operations and make reports quickly to system 2.

{b} System 2-C. As above, it has to assess consequences and implement measures within its operations and make reports quickly to system 2.

{c} System 2. By receiving such information it takes fast corrective action, either through the channels that connects systems 2-A, 2-B and 2-C (see Fig. 3) or via system 3 (i.e. the connections between system 3 and systems 1-A, 1-B and 1-C as shown in Fig. 2).

In what follows two questions will be addressed: first, whether system 2-A communicated about the 'change of plans' to {a}, {b} and {c}. Second, what actions did {a}, {b} and {c} take, if any, about the 'change' (assuming that they received such information).

Table 5
System 2-C; 'Movement of 'S&C' materials operations' (see Figs. 2 and 3)

Action point	Required by the RSSMS System 2-C description	'Possession management' at the time of the accident Engineer Supervisor Mr Evans performed the function associated with system 2-C
11	Relevant information to system 2-C related to the task of moving S&C materials.	This channel of communication was in place in the form of supervision by Mr Evans.
12	Interpretation of the information being received from the operations (e.g. any change from a pre-planned work activity within system 1-C) needs to be communicated to actions '13' and '12A' as indicated in Fig. 3.	At 0330 Mr Evans completed the work at Lime Street then he decided to move his 'gang' to Edge Hill station. His next task was to move rails by along the Down Fast line towards the Marker Boards of the worksite containing the Engineer's train '7L42'.
12A	(a) Receives information from system 2.	(a) PICOP (Mr Rousell) did not perform this activity efficiently; for example, he did not issued an ES forms in order to proceed with the new task described above.
	(b) Receives information from systems 2-A and 2-B through actions '2A' and '7A' respectively.	(b) Mr Evans did not receive any information from systems 2-A and 2-B about the changes they made from the pre-planned work.
	(c) Communicates about any change from a pre-planned work activity within system 1-C to: •System 2-A •System 2-B	(c) Unclear whether he advised the other Engineering Supervisors; i.e. •Mr Goulding (system 2-A). •Mr White (system 2-B) when he arrived at Edge Hill.
13	Receives information about the new change from action '12' and assesses its consequences.	Mr Evans arranged with the signaller about the new plan.
14	Planning and taking measures in order to respond appropriately to the 'new change' (rules and regulations applicable to the situation).	There were deficiencies on Mr Evans' actions; for example, he did not arrange the erection of Mark Boards at either side of the worksite. He did not complete the ES documentation for the first worksite. Set up an unplanned worksite and without documentation.
14A	Communicate about the 'new change' to system 2 (see Fig. 3).	Mr Evans advised the PICOP when he arrived at Edge Hill.
15	Implementation of 'measures' to prevent the 'new change' leading to a dangerous incident.	It did not happen.

4.2.1.1. Communication between system 2-A and {a}, {b} and {c}. *Communication between system 2-A and system 2-B*. Table 3 shows that Mr Goulding performed part of the activities associated with system 2-A; i.e. those associated with actions '2', '2A', '3', '4' and '4A' of Fig. 3. However, there is no evidence to suggest that communication took place, about the change of plans, between Mr Goulding and Mr White.

Communication between system 2-A and system 2-C. Mr Evans performed the activities associated with system 2-C as described in Table 3. Again, there is no evidence to suggest that communication took place, about the change of plans, between Mr Goulding and Mr Evans.

Communication between system 2-A and system 2. The PICOP, Mr Russell, performed the activities associated with system 2. Mr Goulding advised the PICOP about the change of plans (see action point '4A' in Table 3 and Fig. 3).

4.2.1.2. Actions taken by {a}, {b} and {c}. *Action(s) taken by system 2-B*. Mr White did not take any action concerning the change of plans of system 1-A.

Action(s) taken by system 2-C. As above, Mr Evans did not take any action regarding the change of plans of system 1-A.

Action(s) taken by system 2. As it was mentioned above, by receiving information about the change of plans of system 1-A enables system 2 to take a 'higher' view of the total consequences of such change and to take fast corrective action via systems 2-A, 2-B and 2-C or via System 3. However, there were deficiencies in the actions which followed as shown in Table 3.

4.2.2. Case 2: change of plans in system 1-C (see action point '12' in Table 5 and Fig. 3)

The work planned for the original possession arrangement appointed to Mr Evans was: "the task of moving S&C material" (Railtrack, 1999) between Edge Hill and Lime Street.

Once the above work had been completed he moved his 'gang' (i.e. track-workers) to Edge Hill station to move rails. This work was unplanned and not part of the original possession arrangement.

The function of system 2-C is to communicate about the 'change' simultaneously to:

{a} System 2-A. Once the information has been received; it has to detect consequences and implement measures within its operations and make reports quickly to system 2.
{b} System 2-B. As above, it has to detect consequences and implement measures within its operations and make reports quickly to system 2.
{c} System 2. By receiving such information it takes fast corrective action, either through the channels of communication that connects systems 2-A, 2-B and 2-C (see Fig. 3) or via system 3 (i.e. the connections between system 3 and system 1-A, 1-B and 1-C as indicated in Fig. 2).

As with case 1 the two questions addressed were: first, whether system 2-C communicated about the 'change of plans' to {a}, {b} and {c}. Second, what actions did {a}, {b} and {c} take, if any, about the 'change' (assuming that they received such information).

4.2.2.1. Communication between system 2-C and {a}, {b} and {c}. *Communication between system 2-C and system 2-A*. There were deficiencies of communication, about the change of plans, between Mr Evans and Mr Goulding (see Table 5).

Communication between system 2-C and system 2-B. Again, there were deficiencies of communication, about the change of plans, between Mr Evans and Mr White (see Table 5).

Communication between system 2-C and system 2. Mr Evans advised the PICOP about the change of plans (see action '14A' in Table 5 and Fig. 3).

4.2.2.2. Actions taken by {a}, {b} and {c}. Action(s) taken by systems 2-A. Mr Goulding did not take any action concerning the change of plans of system 2-C.

Action(s) taken by systems 2-B. As above, Mr White did not take any action regarding the change of plans of system 2-C.

Action(s) taken by system 2. Deficiencies of the activities associated with system 2 (PICOP). First, deficiencies in communication; i.e. there was no communication about the change of plans to systems 2-A and 2-B. Second, deficiencies in the process of issuing ES forms. ES forms are required to be issued by the PICOP for each activity that needed to be carried out in the possession. This was a requirement by the Rule Book Section T(iii) (RSSB, 2003). For example, a new ES form was not issued for the new activity as a consequence of the change of the original plan (Railtrack, 1999).

From the above two cases, it is clearly seen that the system in place at the time of the accident lacked an effective co-ordination system. It also raises the question whether the 'T(iii)' of the Rule Book (RSSB, 2003) dealt explicitly and consistently with the co-ordination system such as that shown in Fig. 3.

4.3. System 3: safety-functional

This system is directly responsible for maintaining risk within an acceptable range in the operations of system 1 and ensuring that system 1 implements the organization's safety policy.

The Permanent Way Section Manager, Mr McStein, performed part of the activities associated with system 3. There were deficiencies associated with his functions as described in the following paragraphs.

4.3.1. System 3 and system 2 channel

The evidence shows that the only indication of communication between the PWSM and the PICOP (see Fig. 2) were the following:

{a} At the pre-planning meeting of the possession arrangements where the PWSM selected Mr Russell as the PICOP for the 'T(iii) possession'. However, there were deficiencies in the actions of the PICOP.
{b} The PICOP "did not keep a written record of the arrangements made at the pre-planning meeting" (Railtrack, 1999, p. 12).
{c} There is no evidence of the PWSM on duty during the maintenance work. Thus, it is unclear who performed the actions associated with system 3 at the time of the accident.

4.3.2. System 3 and system 1-B channel

Deficiencies in the actions of the PWSM; for example:

{a} He did not attempt to call Mr White in order to attend the pre-planning meeting held at the same building.
{b} He did not attempt to obtain Mr White's mobile telephone number and pass it to the supervisors and to the PICOP.

4.4. System 3: safety-audit*

System 3* is part of system 3 and its function is to conduct audits sporadically into the operations of system 1. System 3* intervenes in the operations of system 1 according to the safety plans received from system 3. System 3 needs to ensure that the reports received from system 1 reflect not only the current status of the operations of system 1, but are also aligned with the overall objectives of the organization.

{a} There is no evidence of any activity associated with system 3* at the time of the accident.
{b} There is no evidence that there were inspections on the activities in the possession at the time of the accident.

4.5. System 4: safety-development

System 4 is concerned with safety R&D for the continual adaptation of the railway system as a whole. By considering strengths, weaknesses, threats and opportunities, system 4 can suggest changes to the organization's safety policies. However, it is unclear whether the function associated with system 4 was in place at the time of the accident. Three examples related to the 'environmental' factors:

According to a study conducted on "Root causes of red zone working", the following was found:

In relation to 'economical drivers':

> "Pressures for getting the work job mean that the safest forms of protection are often not used, and corners are frequently cut in order to get the job done. Workers frequently feel that there is insufficient time available to get the work done safely". (Vijendran and Beard, 2003, p. 216)

In relation to 'cultural preferences':

> "Culturally, there persists a lack of motivation amongst track-workers to pursue Green Zone working and in some cases workers have a preference for working in Red Zones". (Vijendran and Beard, 2003, p. 216)

And in relation to track-worker perceptions of 'Red Zone Working':

> "You have to be able to work with trains running past you" "I prefer it – it's 'Mission impossible' stuff". (Vijendran and Beard, 2003, p. 217)

It is not clear whether the 'management of possessions' considered explicitly the function associated with system 4.

4.6. System 4: safety-confidential reporting system*

System 4* is part of system 4 and is concerned with confidential reports or causes of concern from any employee, about any aspects, some of which may require the direct and immediate intervention of system 5. It did not exist at the time of the fatal accident. For example, the failure of Mr White to arrange the erection of Marker Boards was not reported as indicated in the two examples below:

According to the report on the accident, it stated that:

> "Looking towards Lime Street, Mr Evans could clearly see the Marker Boards of the worksite where 7L42 was working but looking towards Edge Hill East Junction, he saw the tamping machine quite clearly but did not see any Marker Boards protecting the tamping operations". (Railtrack, 1999, p. 14)

> "The tamper operators and boxing-in gang ... did not query the lack of Marker Boards as they were under the false impression that the tamper was the only "train" in the possession". (Railtrack, 1999, p. 20)

4.7. System 5: safety-policy

System 5 is responsible for deliberating safety policies and for making normative decisions. According to alternative safety plans received from system 4, system 5 considers and chooses feasible alternatives, which aim to maintain the risk within an acceptable range. Clearly there were deficiencies of the activities associated with system 5. The immediate and all the underlying causes of the accident identified above are an indication of the failure to device and implement adequate safety policies.

4.8. Summary of the findings

A summary of the causal factors of failure of systems 1–5 found in the analysis of the Edge Hill accident is given below.

4.8.1. Structural organization mappings

4.8.1.1. System 1: safety-policy implementation. Failure of the activities associated with system 1 and specifically the following causal factors:

{1} Missing channel of communication between '*Engineer's scrap train operations*' of system 1-A and '*Tamping operations*' of system 1-B.
{2} Missing channel of communication between '*Engineer's scrap train operations*' of system 1-A and '*Movement of S&C materials operations*' of system 1-C.
{3} Missing channel of communication between '*Tamping operations*' of system 1-B and '*Movement of S&C materials operations*' of system 1-C.
{4} Missing channel of communication between ES Mr Goulding of system 1-A and ES Mr White of system 1-B.
{5} Missing channel of communication between ES Mr White of system 1-B and ES Mr Evans of system 1-C.
{6} Missing channel of communication between ES Mr White of system 1-B and PWSM Mr McStein who performed part of the function associated with system 3.
{7} Missing channel of communication between ES Mr Russell (PICOP) of system 2 and Mr White of system 1-B.

4.8.1.2. System 2: safety-co-ordination. Failure of the activities associated with system 2 and specifically the following causal factors:

System 2-A: (Mr Goulding)

{8} Failed to communicate about the change of the pre-planned work to ES (Engineering Supervisors) that performed the functions associated with systems 2-B and 2-C.

System 2-B: (Mr White)

{9} Failed to perform his activities effectively.

System 2-C: (Mr Evans)

{10} Failed to communicate about the change of the pre-planned work to ES that performed the functions associated with systems 2-A and 2-B.

System 2: (PICOP)

{11} Failed to communicate about the change of the pre-planned work of system 2-A to systems 2-B and 2-C.
{12} Failed to communicate about the change of the pre-planned work of system 2-C to systems 2-A and 2-C.
{13} Failed to issue new ES forms for the removal of rails at Edge Hill station that was not included in the original work planning as required by the Rule Book Section T (iii).

System 3: safety-functional

Failure of the activities associated with system 3 and specifically the following causal factors:

{14} Failure of the PWSM to perform his functions effectively at the pre-planning meeting for the possession arrangements. For example:
{15} There is no evidence of the PWSM on duty during the maintenance work. Thus, it is unclear who performed the function associated with system 3 at the time of the accident.

System 3*: safety-audit

{15} The function associated with system 3* did not exist at the time of the accident.
{16} The channel that connects system 3* to each operation was not in place at the time of the accident (see Fig. 2).

System 4: safety-development

{17} The function associated with system 4 was not in place at the time of the accident.

System 4*: safety-confidential reporting system

{18} The function associated with system 4* was not in place at the time of the accident.

System 5: safety-policy

Failure of the function associated with system 5.

{19} Deficiencies in safety policies on 'possession management'.

4.9. Some 'Learning Points'

{a} The need for an effective 'Maintenance Safety Management System'. Such a system must have all the functions associated with systems 1–5 in place; the channels of communication that interconnects them all in place. Furthermore, it should be clearly stated the roles and responsibilities of those who are going to perform the function associated with systems 1–5.
{b} A 'Strategic Maintenance Group' could perform the functions associated with systems 2–5. The contractors, rail infrastructure owners, TOCs (Train operating Companies) could form part of this strategic group. The main function of the group could be to conduct the strategic planning of track work and coordinate the maintenance work in order to maintain risk within an acceptable range, whatever that might be.
{c} The 'Strategic Maintenance Group' should implement an effective coordination system such as that shown in Fig. 3.

5. Conclusions and future work

A SSMS model has been used to analyse the Edge Hill railway accident. The approach has been to compare the features of the accident with only one characteristic of the model; i.e. the structural organization. The analysis has highlighted systemic failures of the 'possession management' at the time of the accident and in particular, failures of the activities associated with systems 1–5 as well as missing channels of communication amongst those involved in track-side maintenance work. The SSMS has shown in itself that can be used as a tool for examining past failure, either major ones involving multiple fatalities or relatively minor ones such as those that may arise from the 'management of possessions'. This may be done via a process of comparison between the 'real-world' situation and the model. A system or channel of communication in the model may not exist in the real-world case. Also, even if a system or channel of communication is nominally in place, it may not function effectively. More work is needed in order to illustrate the full potentiality of the model. For instance, a detailed analysis of the Piper Alpha disaster (Cullen, 1990) and the Channel Tunnel fire (CTSA, 1996) would give the benefit of showing all the fundamental characteristics of the model (see Table 1). Also, it would be desirable to compare the model with other accident analysis approaches (e.g. MORT) by analysing the same failed system. More generally, it should be borne in mind that the SSMS model is generic. The SSMS can be applied: {a} re-actively, to examine a failed system, e.g. Edge-Hill railway accident; {b} pro-actively, either to design a new SMS or to examine a system which has not yet failed. It is hoped that this approach will lead not only to more effective management of safety in the 'management of possessions', but also to more effective management of safety for any organization.

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