ESTABLISHING THE RELATIONSHIP BETWEEN RAILWAY SAFETY AND OPERATIONAL PERFORMANCE

WENDY D. WEMAKOR, ANSON JACK & FELIX SCHMID
Birmingham Centre for Railway Research and Education, University of Birmingham, UK

ABSTRACT

Deregulation and/or privatization of railway systems has been adapted in many developed countries, aimed at improving economic performance. Literature on railway performance mainly focuses on the effects of reforms and on liberalization itself as well as measuring performance indicators for the management of assets in the railway industry. Although these management reforms on the maintenance and operations of rail infrastructures are generally found to have contributed to improving trends of rail safety and safety performance, there is not much evidence from research to support this. There is also little work on how the lessons from restructuring can apply in developing countries.

Identifying approaches that can revitalize railways in developing and emerging economies while raising standards of safety and operational performance is the objective of this article. Presented are some of the specific lessons from developed countries and how they can be applied in developing economies' railways, noting that it is not generally feasible to adopt best practices because of social and/or economic constraints. Only where there is a significant foreign investor is there the potential to replicate best in class technology and operational practices, so the presentation will identify areas where less well-funded railways can adopt lessons from developed countries – using both historical and current international benchmarks.

The originality of this approach lies in establishing the relationship between performance and safety in the era of reforms and liberalization of the rail industry. The article analyses publicly available data to suggest how rail safety considerations have impacted in a more general way upon railway performance, and by extension, derive lessons for emerging and developing economies.

Keywords: benchmarking, operational performance, railway, safety, safety performance

1 INTRODUCTION

Cities all over the world are growing rapidly with ever more intensive human interactions, dense vehicular flows and vigorous commercial activities. In many cities, faster, more reliable and efficient modes of transport are required to support the sustainable growth and development of their economies. Unfortunately, many developing and emerging economies are lagging in the provision of sustainable transport means for their people.

The growth and development of the railway industry in many developing countries has been extremely slow since its inception more than a century ago. Railways are now the least developed mode of transport as road transport is the dominant mode in most of these developing countries. As a product of the colonial period, railways of tropical Africa were built from ports into the inland to facilitate the export of minerals and agricultural products as well as the import of finished goods [1, 2].

Although rail networks are identified as an important element of the transportation system for economic growth and development of many countries, Ghana's rail network, like some other rail networks in developing countries, has not changed since the 1960s [2, 3]. Bullock [1] in his study on sub-Saharan African railways describes the existing African railway system as fragmented with lines connecting cities within a country or originally linking a port to its immediate hinterlands despite proposed master plans for an integrated rail system. It must be noted that this is not the case for all rail networks in Africa as there are a few significant international networks such as the North African network in

ISSN: 2058-8305 (paper format), ISSN: 2058-8313 (online), http://www.witpress.com/journals
DOI: 10.2495/TDI-V2-N1-98-114

Maghreb linking Morocco, Algeria and Tunisia; South Africa's network which extends to the Democratic Republic of Congo and Tanzania; as well as the East African rail network linking Kenya, Uganda and Tanzania.

Over the years, rail transport in developing countries has seen a decline in passenger numbers and passenger kilometres travelled because of competition from road transport [1–3]. Although traffic densities are generally low, specialized mineral lines in West and Southern Africa carry more than half of sub-Saharan railway's total freight measured by net ton-km [1]. The decline in patronage of rail transport is mainly attributed to the neglect of the railway sector by governments, involving poor quality of service, insufficient funds for expansion projects, deteriorated assets and poor maintenance of tracks and locomotives as a result of the lack of skilled personnel leading in some cases to the collapse of the rail industry in most of these developing countries.

In this regard, the absence of an established railway authority or regulator for the safe operation and maintenance of the almost non-existent rail networks poses a great risk to passengers, workforce and the general public. South Africa's Rail Safety Regulator (RSR) is possibly the only sub-Saharan African country with a well-established rail safety regulating body. As a custodian of rail safety on South African railway lines, the RSR is responsible for the issuance and management of safety permits, the investigation of railway accidents, the conduct of inspections and audits, the development of regulations and safety standards for the formulation of regulatory regimes as well as the issue of notices of non-conformance and non-compliance [4].

With plans in place to rejuvenate the railway systems of developing countries in order to boost economic growth and development; the applicability of best practices of rail operations from developed countries is recommended. To do so an understanding of the physical, social, economic and political environment in which these systems will operate is very necessary and highly required.

2 RAILWAY PERFORMANCE DATA

By presenting a case study of the British railway network (which has a vast amount of publicly available data) this provides the opportunity to grasp an understanding of key performance indicators as well as help define the parameters required to establish a more detailed understanding of the relationship between railway safety and operational performance. In this respect, the main units of analysis for this study are passenger train operating companies (TOCs) and the railway network infrastructure management companies of Britain's railway industry.

Great Britain's railway is generally acknowledged to be the safest major railway network in Europe and among the safest in the world, as demonstrated by data published by the Office of Rail and Road (ORR). ORR is 'the independent safety and economic regulator for Britain's railways as well as monitor of Highways England' publishes a great deal of statistics on railway performance, rail usage and safety [5, 6]. According to Gower [7], passenger performance is assessed using performance metrics such as the Public Performance Measure (PPM) and Cancellations and Significant Lateness (CaSL) with the performance data supplied by Network Rail. Network Rail is Britain's dominant railway infrastructure management company and hence the source of all infrastructure-related data used in this analysis.

The PPM is a key performance metric for the evaluation of overall performance and reliability of train services. This therefore makes it 'the main cross-industry measure of operational performance for all passenger services' [8]. It is defined as the percentage of passenger trains that arrive at final destinations on time. That is, trains that arrive at their final destination within 5 or 10 min (for long-distance services) of their scheduled arrival time [7]. Similarly, CaSL is defined as the percentage of passenger trains that are cancelled either in part or full and/or arrive at final destinations 30 or more minutes later than the scheduled arrival time [7, 9]. It was developed as a supplementary measure to ensure that trains are not 'written off' by companies once they exceed their PPM threshold [8]. It is a very useful measure in terms of performance recovery and also incentivizes companies and their controllers and signallers to ensure that trains do not arrive later than 30 min. The term cancellation is used when a train fails to depart from its point of departure or when a train is terminated before it reaches its destination. Two main types of cancellation according to ORR [8] are as follows:

- Full – where the train failed to run entirely or ran less than 50% of booked mileage or called at less than 50% of booked stations. Trains that arrive over 119 min late are counted as full cancellations.
- Part – where the train terminated short of destination or started beyond origin (or both). Trains that fail to call/stop at, at least one booked station are counted as part cancellation.

In addition, a moving annual average is calculated for both PPM and CaSL to reflect the proportion of trains on time as well as those cancelled or significantly late within the last 12 months. In calculating the CaSL data, the total number of passenger trains cancelled and significantly late between 30 and 119 min is divided by the number of scheduled trains, which is then expressed as a percentage [8]. The lower the figure, the fewer the CaSL of passenger train services. The ORR also publishes total delay minutes by TOC which reflects performance of the individual TOCs. The total delay minutes are further categorized into Network Rail-on-TOC-related delays, TOC-on-Self-related delays and TOC-on-TOC-related delays. PPM, CaSL and total delay minutes categorized by TOCs are therefore the operational performance data used in the study.

Generally, safety is measured by the number of accidents and its consequences that may occur at home, the workplace, school or on any mode of transport. In the British rail industry, rail safety is measured by the fatalities and weighted injuries, hence the reporting of occurrences in the operation of trains and maintenance of railway infrastructure is the major source of rail safety data. There is therefore the need to link the number of accidents and the related number of victims to rail traffic performance to measure relative safety [10] often expressed in passenger-kilometres and ton-kilometres. According to Network Rail [9, 11] the passenger safety indicator is used to measure the level of passenger safety on a network and it is derived from two data sources. These are the train accident risk data from the Precursor Indicator Model (PIM) and the weighted fatality and injury data from station level crossings and Network Rail managed stations [9].

The PIM, provided by the Rail Safety and Standards Board (RSSB) on a quarterly basis, tracks changes in accident precursors to measure the underlying risk from train accidents and is also calibrated against the safety risk model (SRM) [12]. Due to the rare nature of train accidents, precursors help indicate the risk of accident occurrence although more often than not, these do not result in an actual accident. PIM therefore demonstrates quantified changes in the underlying risk over a period. In other words, it provides a day-to-day review of the main elements of train accident risk, that is the risk of collisions, derailments and fires [12], which are reported/recorded by TOCs into the RSSB's Safety Management Intelligence System (SMIS).

According to the UK Health and Safety Executive (cited in [13]), 'an accident is any unplanned event that results in injury, and/or damage and/or loss'. Alternatively, a precursor is an event or condition which indicates the existence of a higher level of risk or a top event which is often defined as a serious incident that may be the immediate cause of a death or injury [13, 14]. The difference, however, between accidents and top events is the consequence of the event. That is, a top event qualifies as an accident only in situations where there are injuries, death or serious damage to property [12].

Risk, in the context of the RSSB's SRM, is 'an estimate of the potential harm to passengers, staff and members of the public from the operation and maintenance of the railway' [15]. Therefore, the risk (the average number of fatalities or equivalent fatalities per year) associated with an event is calculated as the product of the frequency and consequences. That is:

$$\text{Risk (FWI/year)} = \text{Frequency (events/year)} \times \text{Consequence (FWI/event)} \tag{1}$$

Signal passed at danger (SPAD) risk data is an example of data that can be found in SRM. Other precursor indicator measures in SRM are infrastructure failures, infrastructure operations, train operations and failures and/or level crossings. For the purpose of this research, SPAD risk rates will be the measure of safety performance due to data availability at the time of the study. The choice of parameters has been based on the availability of data within a significant period (preferably 2006–2016) for which the data will have the ability to reflect trends or patterns for meaningful comparison/analysis.

Out of a total of 25 passenger TOCs operating on British railways, serving as a sampling frame, focus is placed on 17 franchised TOCs based on the availability of SPAD risk data between the time periods 2006–2016. SPAD risk data is significant to this research as it is an important element of railway safety performance. According to the European Railway Agency [16], 'a safe railway is more efficient and a more attractive transport choice, enabling society to address the environmental and economic challenges of the 21st century'. In Europe, the European Union (EU) member states are required by the EU Railway safety directive (2004/49/EC) to ensure the maintenance of safety as well as continuous improvement where reasonably practicable [17, 18].

3 FINDINGS AND DISCUSSIONS

Testing the defined set of parameters below is mainly aimed at determining mathematically/statistically the existence of a relationship between railway safety and operational performance. Using available data from the ORR and RSSB on the selected 17 TOCs with respect to PPM, CaSL, TOC-on-Self-delay minutes and SPAD risk rates, the processes involved in establishing a correlation are discussed. It must be noted that TOC-on-Self-delay minutes are first used based on the notion of focusing on parameters within the managerial control of TOCs.

3.1 Hypothesis test

H_0*: safety and operational performance are independent*
H_1*: safety and operational performance are (negatively or positively) associated*

First, TOCs were ranked by performance for each performance indicator (both safety and operational performance data) per year over the 10-year period as illustrated in Table 1. It must be noted that, for a high-performance ranking of 1, PPM was based on the highest

Table 1: TOCs performance ranked for the period 2006–2016 using ORR available data (Source: Author's Construct, 2016).

		2006			2007				2008				2009	
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	86.50	4.49	100	91.81	2.88	0.58	9251	2.65	0.99	265,531	94.89	186	0.48	206,581
c2c	94.15	2.23	100	94.50	2.88	0.00	9486	2.05	0.49	25,549	96.21	138	0.47	20,572
Chiltern Railways	93.98	1.57	100	94.37	1.90	0.34	9527	1.39	0.50	45,041	95.48	143	0.32	54,009
CrossCountry	85.01	6.92	100	86.32	6.79	0.50	8952	5.10	0.32	123,663	90.69	459	0.65	96,886
East Midlands Trains	86.56	3.52	100	86.54	4.56	0.27	8838	3.57	1.04	129,044	92.35	223	0.22	107,383
First TransPennine Express	88.34	4.83	100	91.57	4.14	0.55	9014	4.71	0.31	–	92.30	346	0.69	–
Govia Thameslink Railway	89.48	2.83	100	89.27	2.93	0.00	9104	2.56	0.00	503,904	89.97	338	0.00	528,805
Great Western Railway	84.02	3.34	100	82.39	4.57	0.94	8897	2.58	0.69	370,583	92.27	231	0.49	383,577
Greater Anglia	87.37	2.57	100	89.80	2.44	0.91	9070	2.15	1.09	216,498	91.07	229	0.95	212,798
London Midland	86.57	3.23	100	88.42	3.29	4.41	8755	3.75	0.74	199,242	88.37	343	0.76	175,070
London Overground	91.29	3.52	100	91.06	3.75	21.08	9275	2.11	140	50,805	92.69	250	1.86	45,957
Merseyrail	92.56	3.11	100	94.29	2.65	1.38	9469	2.53	1.08	32,364	96.22	191	0.80	23,643
Northern	87.18	2.23	100	88.31	2.53	0.65	8915	2.56	0.90	590,166	91.70	197	0.69	569,669
ScotRail	88.56	2.17	100	90.11	2.17	1.08	9085	2.16	0.53	265,450	90.58	222	0.42	306,232
South West Trains	90.48	2.34	100	91.47	2.02	1.18	9328	1.80	100	230,986	92.95	222	0.51	236,317
Southeastern	88.69	2.05	100	89.62	2.23	1.48	9100	1.99	114	322,033	90.05	306	0.88	320,135
Virgin Trains West Coast	87.19	4.38	100	85.89	5.20	0.21	8247	7.06	0.36	101,571	82.89	671	0.09	121,833

	2010				2011				2012				2013			
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay minutes	PPM	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	9427	2.28	0.91	230,217	93.79	2.41	0.91	241,469	93.52	241	0.76	219,276	9336	250	0.83	212,023
c2c	9509	2.04	0.00	24,257	96.57	1.42	0.24	15,049	97.44	102	119	17,770	9691	132	0.72	14,065
Chiltern Railways	9426	1.69	0.84	73,087	92.78	1.92	0.48	102,385	94.67	144	0.29	77,137	9510	134	0.14	66,903
CrossCountry	8798	5.58	0.46	95,709	89.08	4.44	0.20	68,047	87.80	539	0.15	71,354	8729	475	0.25	74,597
East Midlands Trains	9214	2.49	0.36	98,469	93.11	1.94	0.43	72,094	93.18	213	0.72	81,781	9118	278	0.43	92,513
First TransPennine Express	9068	4.44	0.29	21,820	93.03	2.78	0.29	16,383	92.80	305	0.38	16,995	8992	492	0.10	16,841
Govia Thameslink Railway	8914	3.60	0.00	517,051	90.29	2.91	0.00	515,373	88.95	303	0.00	564,987	8673	423	0.00	555,950
Great Western Railway	9075	2.66	0.68	364,648	90.33	2.48	0.53	329,205	89.54	289	0.68	354,218	8871	298	0.61	333,713
Greater Anglia	8904	2.66	0.45	242,507	89.70	2.40	0.83	209,811	91.04	225	0.47	183,547	9039	250	0.90	166,302
London Midland	9008	2.65	0.55	164,595	89.85	2.73	0.49	142,739	87.74	355	0.55	207,286	8514	384	0.66	201,446
London Overground	9384	2.68	0.67	68,214	95.72	1.83	2.14	47,823	96.10	168	110	40,223	9560	188	1.83	40,707
Merseyrail	9535	2.06	2.38	36,078	95.07	2.09	1.23	31,123	95.32	236	0.49	36,361	9560	186	1.23	39,354
Northern	9064	2.24	0.79	556,043	91.53	1.88	0.68	509,436	91.35	185	0.39	528,228	9048	190	0.78	501,340
ScotRail	8996	2.76	0.73	364,858	89.78	2.89	0.88	288,746	92.93	161	0.36	254,477	9108	205	0.46	279,952
South West Trains	9343	1.75	1.05	193,814	92.54	1.97	0.85	207,888	91.62	207	0.60	212,368	9068	251	0.85	211,626
Southeastern	8769	3.85	1.11	364,742	91.43	2.36	1.09	316,545	91.60	225	0.76	285,608	8979	301	0.77	286,684
Virgin Trains West Coast	8549	5.56	0.31	117,395	85.84	4.55	0.31	93,589	85.72	430	0.04	115,286	8389	536	0.27	88,928

	2014				2015				2016			
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	92.39	285	1.11	242,615	92.88	2.53	0.60	235,581	9205	2.76	0.85	76,256
c2c	96.58	149	0.00	16,281	97.13	1.10	0.47	22,896	9583	1.53	0.00	10,898
Chiltern Railways	94.78	175	0.87	62,636	94.28	1.54	0.28	88,103	9521	0.94	0.00	27,931
CrossCountry	87.15	501	0.00	71,858	89.40	4.01	0.19	71,116	9054	3.75	0.21	18,898
East Midlands Trains	91.78	200	0.43	88,378	92.74	2.01	0.35	82,300	9327	2.10	0.44	24,328
First TransPennine Express	88.69	434	0.26	19,135	88.32	5.26	0.24	18,897	8904	5.51	0.19	4,633
Govia Thameslink Railway	84.10	457	0.00	672,567	81.55	5.40	0.56	908,203	8014	5.40	1.18	409,223
Great Western Railway	87.66	352	0.38	331,844	89.45	2.57	0.78	315,992	9124	2.53	0.63	98,199
Greater Anglia	89.63	266	0.94	172,542	89.60	2.76	0.36	209,905	9018	2.68	0.71	59,212
London Midland	87.46	300	0.66	208,169	87.84	2.92	0.89	217,461	8981	2.51	0.27	57,884
London Overground	95.53	171	0.82	39,981	94.20	2.17	0.51	58,088	9465	1.85	1.67	12,996
Merseyrail	95.69	187	0.98	39,859	95.43	1.90	0.72	41,140	9545	2.02	0.00	11,153
Northern	90.86	179	0.63	550,933	90.95	1.66	0.55	493,778	9178	1.69	0.21	141,127
ScotRail	91.44	199	0.55	317,353	90.34	2.58	0.58	312,319	9078	2.36	0.29	100,602
South West Trains	89.17	308	0.56	228,835	90.37	2.58	0.86	260,900	8922	3.04	0.85	80,324
Southeastern	88.00	324	1.00	302,550	88.46	3.18	0.95	347,590	8528	4.14	0.59	77,173
Virgin Trains West Coast	85.22	489	0.18	90,921	85.74	4.95	0.22	87,921	8605	4.41	0.00	21,401

	2006				2007			2008			2009			
Passenger Train Operating Company	PPM	CaSL	SPAD Risk Rate	Celay Minutes PPM	CaSL	SPAD Risk Rate	Celay Minutes PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	13	15	1	4	9	8	6	12	11	13	4	3	7	11
c2c	1	4	1	1	5	1	2	4	5	2	2	1	6	2
Chiltern Railways	2	1	1	2	1	5	1	1	6	4	3	2	4	5
CrossCountry	16	17	1	15	17	6	12	16	3	7	12	16	10	6
East Midlands Trains	15	13	1	14	14	4	15	13	13	8	7	8	3	7
First TransPennine Express	9	16	1	5	13	7	11	15	2	1	8	15	11	1
Govia Thameslink Railway	6	8	1	11	10	1	7	10	1	16	15	13	1	16
Great Western Railway	17	11	1	17	15	11	14	11	8	15	9	10	8	15
Greater Anglia	10	7	1	9	6	10	10	6	15	10	11	9	16	10
London Midland	14	10	1	12	11	16	16	14	9	9	16	14	13	9
London Overground	4	12	1	7	12	17	5	5	17	5	6	11	17	4
Merseyrail	3	9	1	3	8	14	3	8	14	3	1	4	14	3
Northern	12	5	1	13	7	9	13	9	10	17	10	5	12	17
ScotRail	7	3	1	8	3	12	9	7	7	12	13	7	5	13
South West Trains	5	6	1	6	2	13	4	2	12	11	5	6	9	12
Southeastern	8	2	1	10	4	15	8	3	16	14	14	12	15	14
Virgin Trains West Coast	11	14	1	16	16	3	17	17	4	6	17	17	2	8

Passenger Train Operating Company	2010 PPM	2010 CaSL	2010 SPAD Risk Rate	2010 Celay minutes	2011 PPM	2011 CaSL	2011 SPAD Risk Rate	2011 Celay Minutes	2012 PPM	2012 CaSL	2012 SPAD Risk Rate	2012 Celay minutes	2013 PPM	2013 CaSL	2013 SPAD Risk Rate	2013 Celay Minutes
Arriva Trains Wales	3	6	14	11	4	10	14	12	5	11	14	12	5	8	13	12
c2c	2	3	1	2	1	1	3	1	1	1	17	2	1	1	10	1
Chiltern Railways	4	1	13	5	7	4	7	8	4	2	4	6	4	2	3	5
CrossCountry	15	17	7	6	16	16	2	5	15	17	3	5	14	15	4	6
East Midlands Trains	7	7	5	7	5	5	6	6	6	7	13	7	6	10	6	8
First TransPennine Express	9	15	3	1	6	13	4	2	8	14	6	1	11	16	2	2
Govia Thameslink Railway	13	13	1	16	12	15	1	17	14	13	1	17	15	14	1	17
Great Western Railway	8	9	10	13	11	11	9	15	13	12	12	15	13	11	8	15
Greater Anglia	14	10	6	12	15	9	11	11	12	9	8	9	10	7	15	9
London Midland	11	8	8	9	13	12	8	9	16	15	10	10	16	13	9	10
London Overground	5	11	9	4	2	2	17	4	2	4	16	4	2	4	17	4
Merseyrail	1	4	17	3	3	7	16	3	3	10	9	3	3	3	16	3
Northern	10	5	12	17	9	3	10	16	11	5	7	16	9	5	12	16
ScotRail	12	12	11	15	14	14	13	13	7	3	5	13	7	6	7	13
South West Trains	6	2	15	10	8	6	12	10	9	6	11	11	8	9	14	11
Southeastern	16	14	16	14	10	8	15	14	10	8	15	14	12	12	11	14
Virgin Trains West Coast	17	16	4	8	17	17	5	7	17	16	2	8	17	17	5	7

	2014				2015				2016			
Passenger Train operating company	PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	5	9	17	12	5	7	12	11	6	11	15	11
c2c	1	1	1	1	1	1	7	2	1	2	1	2
Chiltern Railways	4	3	13	5	3	2	4	8	3	1	1	8
CrossCountry	15	17	1	6	12	14	1	5	10	13	6	5
East Midlands Trains	6	7	7	7	6	5	5	6	5	6	10	7
First TransPennine Express	11	14	5	2	14	16	3	1	14	17	5	1
Govia Thameslink Railway	17	15	1	17	17	17	10	17	17	16	16	17
Great Western Railway	13	13	6	15	11	8	14	14	8	9	12	14
Greater Anglia	9	8	14	9	10	11	6	9	11	10	13	10
London Midland	14	10	11	10	15	12	16	10	12	8	8	9
London Overground	3	2	12	4	4	6	8	4	4	4	17	4
Merseyrail	2	5	15	3	2	4	13	3	2	5	1	3
Northern	8	4	10	16	7	3	9	16	7	3	7	16
ScotRail	7	6	8	14	9	9	11	13	9	7	9	15
South West Trains	10	11	9	11	8	10	15	12	13	12	14	13
Southeastern	12	12	16	13	13	13	17	15	16	14	11	12
Virgin Trains West Coast	16	16	4	8	16	15	2	7	15	15	1	6

PPM percentage, CaSL on a lowest CaSL percentage, SPADs based on the lowest SPAD risk rate and delay minutes based on the lowest delay minutes for each year.

These rankings were then summed up and ranked again to produce Table 2. This was aimed at identifying the performance of each TOC as per the defined performance indicator over the 10 years' period.

To test the hypothesis, the ranked data were grouped into operational performance and safety performance to plot the correlation graph shown in Fig. 1. Using the Spearman's correlation statistical technique, safety and operational performance data are correlated to establish whether there is a relationship between the two variables.

The result shown in Fig. 1 illustrates a weak negative correlation between the two variables with an R^2 value of 0.05. That is, with a calculated p-value of 0.365 at 5% significance level, H_0 is accepted and H_1 is rejected; hence, in this analysis safety and operational performance are independent variables.

Furthermore, focusing on one high-level measure for safety and operational performance, SPAD risk rates and TOC-on-Self-delay minutes ranked data (as shown in Table 2) were plotted in the correlation graph shown in Fig. 2. The result from the graph however shows a weak positive correlation between the two variables with an R^2 value of 0.03. At 5% significance level, the calculated p-value is 0.508. That is, H_0 is again accepted and H_1 is rejected; hence, safety and operational performance are still found to be independent variables.

Table 2: TOCs total ranked performance for the period 2006–2016 (Source: Author's Construct, 2016).

TOTAL Ranked Performance for 2006–2016				
Passenger Train Operating Company	PPM	CaSL	SPAD	Delay Minutes
Arriva Trains Wales	60	101	126	57
c2c	14	24	53	8
Chiltern Railways	37	20	60	26
CrossCountry	152	175	42	80
East Midlands Trains	92	95	72	43
First TransPennine Express	106	164	45	45
Govia Thameslink Railway	144	144	35	135
Great Western Railway	134	120	92	120
Greater Anglia	121	92	108	84
London Midland	155	127	104	86
London Overground	44	73	144	30
Merseyrail	26	67	123	16
Northern	109	54	92	129
ScotRail	102	77	81	99
South West Trains	82	72	116	92
Southeastern	129	102	137	108
Virgin Trains West Coast	176	176	31	66

Ranks			
PPM	CaSL	SPAD	Delay Minutes
5	10	15	7
1	2	5	1
3	1	6	3
15	16	3	9
7	9	7	5
9	15	4	6
14	14	2	17
13	12	9	15
11	8	12	10
16	13	11	11
4	6	17	4
2	4	14	2
10	3	9	16
8	7	8	13
6	5	13	12
12	11	16	14
17	17	1	8

In this instance, looking at data at an aggregate level has led to the surprise finding of an absence of a relationship between the two variables. In order to establish whether there is a relationship between safety and operational performance, a less aggregate form of the data is tested. In addition, TOC-on-Self-delay minutes are normalized by train kilometres, and a correlation graph for the financial year 2015/2016 is plotted. This results in a weak statistical

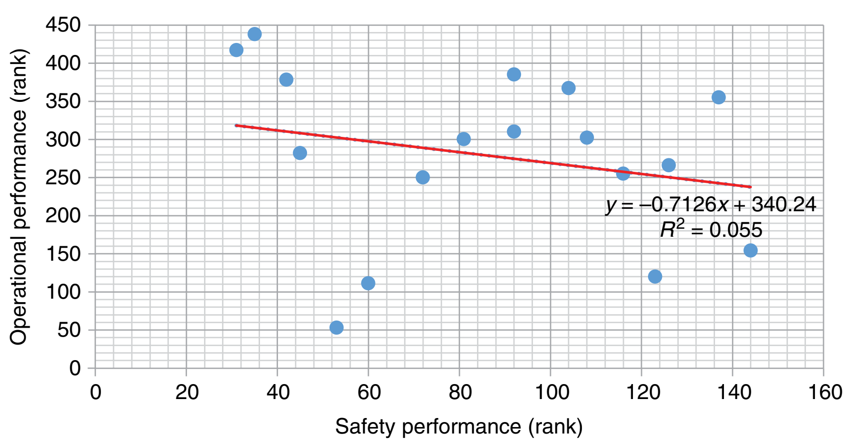

Figure 1: A scatter graph illustrating total ranked operational and safety performance of TOCs for the period 2006–2016 (Source: Author's Construct, 2016).

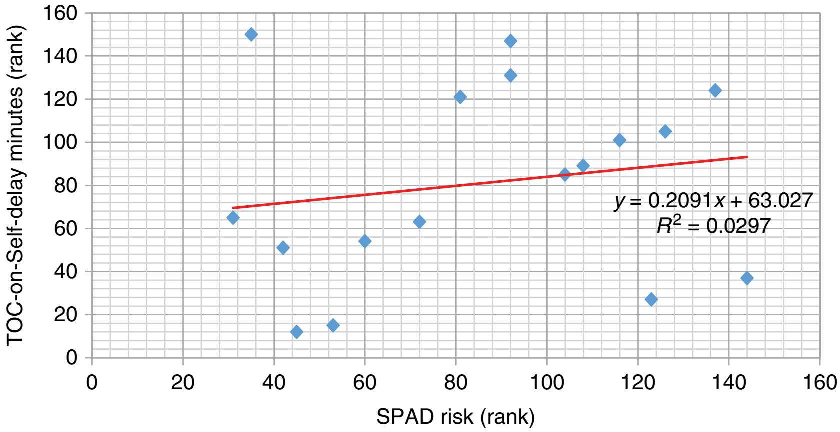

Figure 2: A scatter graph illustrating total ranked delay minutes and SPAD risk of TOCs for the period 2006–2016 (Source: Author's Construct, 2016).

relationship between safety and operational performance. Hence, with a calculated p-value of 0.46, H_0 is once again accepted at a 5% significant level.

A further iteration of the data was done using total delay minutes for the period 2015–2016 normalized by train kilometres and plotted against SPAD risk rate data of the same period. Here, the trend changes showing a stronger positive correlation between the two variables in comparison to the previous tests. Calculated R^2 as illustrated in Fig. 3 is 0.36. With a calculated p-value of 0.01 at 5% significance level, H_0 is rejected and H_1 on the other hand is accepted, hence, beginning to establish a positive association between safety and operational performance.

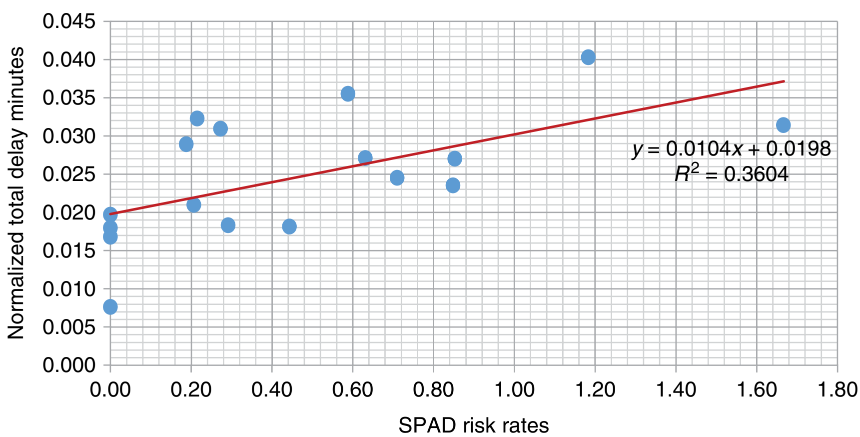

Figure 3: A scatter graph illustrating normalized total delay minutes and SPAD risk rate of TOCs for the period 2015/2016 (Source: Author's Construct, 2016).

Although the research initially focused on TOC-on-Self-delay minutes as a means of concentrating on parameters within the managerial control of TOCs, it is noted that Network Rail-on-TOC delay minutes (contributing 61% of 2015/2016 total delays per available ORR data) are related to safety performance and in effect influence TOCs operational performance. That is, there is a strong positive correlation between normalized Network Rail-on-TOC delay minutes and SPAD risk rate as illustrated in Fig. 4. With a calculated p-value of 0.01 at 5% significance level, H_0 is also rejected and H_1 on the other hand is accepted, hence, establishing a positive association between safety and operational performance.

By adapting a benchmarking methodology of ranking safety and operational performance of TOCs, this helps identify best and worst performers of TOCs in each of the performance areas. From the graph illustrated in Fig. 5, c2c (ranked first in both) and Merseyrail (first in

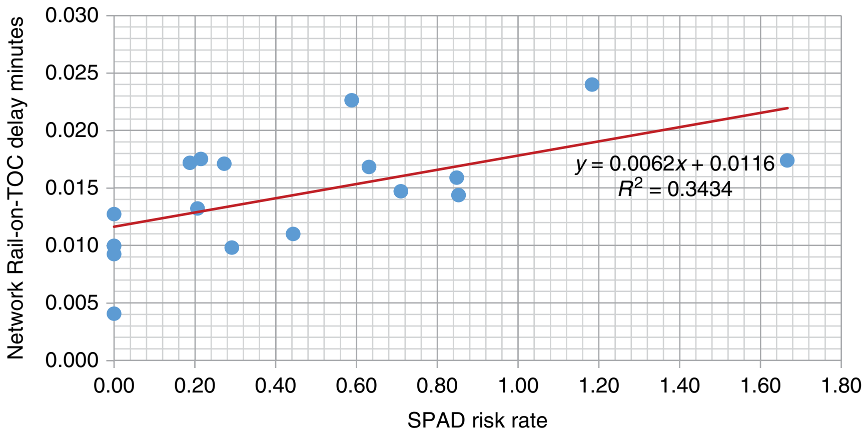

Figure 4: A scatter graph illustrating normalized Network Rail-on-TOC delay minutes and SPAD risk rate of TOCs for the period 2015/2016 (Source: Author's Construct, 2017).

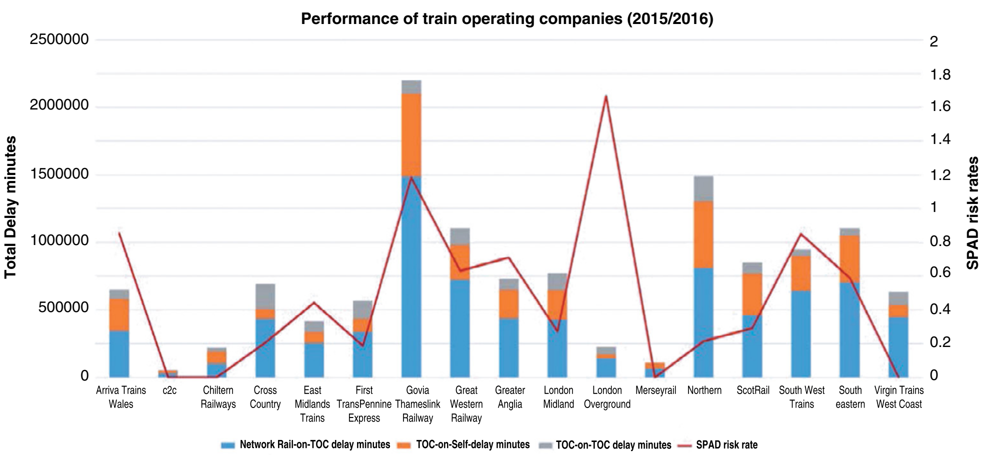

Figure 5: A combined line and stacked bar graph showing 2015/2016 safety and operational performance of TOCs, respectively (Source: Author's Construct, 2017).

safety and second in operational performance) are identified as TOCs with the best performance for both safety and operational performance. Govia Thameslinks Railways is noted to have the second worst performance in both safety (16th) and operational (17th) performance which ascertains the point that Network Rail-on-TOC delay minutes have an influence on TOCs performance as Govia Thameslink Railways experiences the most Network Rail-related delays.

The most interesting performance observed from the graph in Fig. 5 is that of London Overground. With total delay minutes of 772,474 (4th), it experiences the worst safety performance (17th) among the group which could be resulting from the circumstances of its operation. This suggests that there are factors peculiar to influencing only the safety performance of TOCs and alternatively influencing only operational performance or both safety and operational performance of TOCs. A variety of influencing factors may include service type, number of red signals approached on service route, driver communication and training, track and fleet maintenance among others.

In this light, exploring the various underlying factors influencing the safety and operational performance of TOCs while identifying best practices such as safety culture, efficient management of train timetable scheduling among others with the help of a benchmarking methodology is the next phase of this research. At this stage, a much more detailed correlation may be developed with a variety of hypothesis developed from the various best practices identified which may be mapped as one variable and safety performance as another variable.

4 LESSONS LEARNT AND FURTHER STUDIES

To further explain the differences in performance and provide an in-depth understanding of the relationship between safety and operational performance, other high-level measures need to be considered. For instance, aside SPAD risk rates, other indicators such as infrastructure failures, infrastructure operations, train operations and failures and/or level crossings in the SRM need to be considered and explored. Also, the study seeks to further explore the relationship between safety and operational performance by acquiring a more detailed data from RSSB representing daily SPAD incidents occurring between October 2015 and March 2016 to be correlated with daily PPM values within the same period. This is aimed at establishing a stronger statistical relationship between the two variables in order to get a better understanding of the data and relationship between safety and performance.

Moreover, site visits and observation of operational and safety management practices within some selected TOCs are considered to be useful in the benchmarking process for comparison and identification of best practices. This will be useful in recommending certain managerial practices to improve safety and operational performance in TOCs with low performance as well as the rail industry of developing economies who seek to run an efficient, reliable and safe rail transport system. Publication and analysis of data relating to key performance indicators (for both safety and operational performance) is itself a useful tool that may have helped improve performance in the rail industry and may be a lesson that can be suitably translated into developing countries.

5 OTHER OBSERVATIONS

However, in the absence of identified best practices within TOCs at this stage of research, the current features of Britain's rail industry developed over the years through the various decisions and investments made by government and industry could be considered by developing countries in improving their railways. Discussed below are two main observations for developing countries from the view point of this research.

First, the institution of a regulatory body such as ORR could ensure the improvement of safety and performance of the railways. Known to be among the safest railway networks in the world, Britain's railway highlights the possibility that the institution of a regulatory body to ensure safety, value and performance of railways could improve safety and operational performance. A similar body is South Africa's RSR which ensures the improvement of rail safety in the country. By general consensus, South Africa is known to have the most functional railway network in Africa. Developing a hypothesis to test the effect of the presence of regulatory bodies on the performance of rail industries could be useful in the recommendation stage of this research.

In addition, one of the most important observations is the development of a database for the recording and reporting of incidents on the network for which this research may have proved a lot more difficult that it currently is. As seen in the British railway industry, RSSB developed and managed a SMIS to provide a safety reporting system through which research, analysis, standards and insight are used to help the industry deliver a safer, more reliable and sustainable rail system. Rail industries in developing countries do not necessarily need a complex system like SMIS but having a well-defined institution or process to cater for the reporting and management of all forms of incident data on the network could be a useful practice for the industry. Collecting the data is certainly not enough, however, making meaningful analysis in aid of improving performance and influencing decisions in the development of the rail industry and the country as a whole.

6 CONCLUSION

In conclusion, it seems that various decisions and investments made by industry and government over the years to improve railway safety in Britain have in one way or another impacted or influenced operational performance in the industry. The absence of strong statistical evidence at this point of the research does not imply that there is no significant relationship between safety and operational performance as the data were in aggregate form. However, segregating the data with focus on specific events and its impact on both safety and operational performance is the next step and more likely to provide interesting results. This is shown in the 2015–2016 correlation results discussed earlier. It is also evident that the railway system is a very complex one, and when high-level performance indicators that may be expected to correlate are found not to do so shows that a 'deeper dive' is needed into the relationships to test the original hypothesis. This itself is a lesson for all developing railways for which the publication and analysis of data relating to key performance indicators, in both operation and safety, can be an aid in improving performance of the rail industry

REFERENCES

[1] Bullock, R., Off Track: Sub-Saharan African Railways. *Africa Infrastructure Country Diagnostic Background Paper 17, The World Bank: Washington*, 2009.

[2] Due, J. F., The problems of rail transport in tropical Africa. *The Journal of Developing Areas*, **13**(4), pp. 375–393, 1979.

[3] Konadu-Agyemang, K. & Asante, C., Reinventing Africa's socio-economic development through international tourism trade: the case of Ghana. *African Geographical Review*, **23**(1), pp. 23–47, 2004. DOI: 10.4324/9780203197554.

[4] Railway Safety Regulator; About Us, Available at http://rsr.org.za/home/AboutUs. Accessed on: 13 Apr. 2017.

[5] Office of Rail and Road; About ORR, Available at http://orr.gov.uk/about-orr. Accessed on: 29 Apr. 2017.

[6] Office of Rail and Road; Statistic, Available at http://orr.gov.uk/statistics. Accessed on: 29 Apr. 2017.

[7] Gower, T. L., Passenger and Freight Rail Performance 2015-16 Q3 Statistical Release, *Office of Rail and Road: London*, 2016.

[8] Office of Rail and Road, Passenger and freight rail performance: quality and methodology report, *Office of Rail and Road: London*, 2015.

[9] Network Rail, Annual Return, 2010. Available at http://www.networkrail.co.uk/epdf/docs/annual-return-2010/page_156.pdf. Accessed on 18 April, 2016.

[10] EUROSTAT, Statistics Explained: Railway safety statistics, 2016. Available at http://ec.europa.eu/eurostat/statistics-explained/index.php/Railway_safety_statistics. Accessed on 23 February, 2016.

[11] Network Rail, Passenger Safety, 2017. Available at http://www.networkrail.co.uk/aspx/11937.aspx. Accessed on 15 March, 2017.

[12] Rail Safety and Standards Board, Precursor Indicator Model for train accident risk, 2017. Available at https://www.rssb.co.uk/risk-analysis-and-safety-reporting/risk-analysis/precursor-indicator-model. Accessed on 18 March, 2017.

[13] Kyriakidis, M., Hirsch, R. & Majumdar, A. Metro railway safety: An analysis of accident precursors. *Safety science*, **50**(7), pp. 1535–1548, 2012.

[14] Kyriakidis et al., Improving railway safety: Global metro railways' precursor and safety maturity performance. *Presentation at International Rail Safety Conference, Hong Kong*, 2010.

[15] Muttram, R., Railway safety's safety risk model. Proceedings of the Institution of Mechanical Engineers, *Part F: Journal of Rail and Rapid Transit*, **216**(2), pp. 71–79, 2002. DOI: 10.1243/09544090260082317.

[16] European Railway Agency, Rail Safety Performance in the European Union, *Valenciennes: France*, 2014.

[17] Brown, J., International benchmarking of rail safety indicators. *NZ Transport Agency research report*, **583**, p. 87, 2016.

[18] Railway Safety and Standards Board, Annual Safety Performance Report 2013/14: A reference guide to safety trends on GB railways, *RSSB: London*, 2014.