Systemic cost of risk for heavy haul operations in South Africa

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ABSTRACT:

This paper compares the systemic cost of risk between the two heavy haul lines and general freight routes on the South African rail network to determine operational resilience of heavy haul rail systems in a growing export market. The Railway Safety Regulator in South Africa requires permitted railway operators to report extrinsic incidents and intrinsic occurrences in a standardised manner, as well as direct costs aggregated for combined categories. Data recorded and categorized since 2009 according to national standards provides insight into route-specific systemic cost of risk when related to the gross domestic product railed over time. The 33,079 intrinsic occurrences and extrinsic incidents were geospatially superimposed to the nearest station on an existing audited rail freight flow model for South Africa. Reported railway occurrence cost was allocated on an average basis to the nearest station associated with an incident or occurrence. A leading business intelligence tool was used to query the combined database. Data was visualized using maps, animations and graphs. Results suggest that over time the heavy haul remote western iron ore export line exhibits superior route-specific systemic cost of risk when compared to the more populous coal export line over difficult terrain in the east, and the various general freight lines. Evidence suggests that, in terms of systemic cost of risk, the heavy haul model is resilient in a growing market. The paper concludes that socio-economic factors, topography, and railway operational considerations contribute to systemic cost of risk.

1 INTRODUCTION

The National Railway Safety Regulator Act No. 16 of 2002 of South Africa as amended (RSR Act) established the Railway Safety Regulator (RSR) as a juristic person comprising of a board, a chief executive and staff. The objects of the RSR are to: oversee safety (the lack of railway occurrences, fatalities, injuries or damage within railway operations) of railway transport while operators remain responsible for such safety within their areas of responsibility; promote improved safety performance in the railway transport industry in order to promote the use of rail as a mode of transportation; develop any regulations that are required; monitor and ensure compliance; and give effect to the objects of the RSR Act. In terms of the RSR Act no railway operator (network, station or train operator) may undertake any railway operation or a component of a railway operation without being in possession of an applicable safety permit.

1.1 *Cost of Risk*

Permitted railway operators must report to the RSR any *railway occurrence*, defined by the RSR Act as a railway accident or railway incident prescribed as such, which could include criminal activity, and the RSR must investigate them. The RSR must establish a national information and monitoring system regarding safe railway operations within the Republic that may include railway occurrences and security matters, and the Minister may make regulations prescribing the format. Railway occurrences can be conveniently separated into extrinsic incidents and intrinsic occurrences.

We define *extrinsic incidents* as security-related events reported by permitted railway operators or the general public to the South African Railway Police Service (SARPS) that fall outside of the normal activities associated with permitted railway operators. Extrinsic incidents are associated with intentional harm or damage to persons or property, and can include criminal activity. It is common cause in South Africa that cable theft and vandalism of metal structures severely impact the integrity of cabled field systems and dominates the extrinsic occurrence count.

We define *intrinsic occurrences* as safety-related operational events reported directly by permitted railway operators to the RSR experienced in the normal cause of business, excluding extrinsic incidents. Since 2006, permitted railway operators have declared railway occurrence event and cost data to the RSR for verification and inclusion in the RSR Database, using a prescribed data format (RSR 2009).

We define *railway occurrence cost* as the direct nominal cost reported to, and collated by, the RSR following any railway occurrence. As more data becomes available this definition may be revised to include consequential costs.

Railway occurrence cost is only meaningful when related to the associated corridor-specific economic activity. The associated economic activity for freight rail is the value of the commodities transported, effectively the transported gross domestic product. For a freight corridor we define *cost of risk* as the ratio of the railway occurrence cost to the nominal value of the commodity transported, both normalized for volume to Rand per metric tonne expressed as a percentage.

Since operating cost of a railway system is primarily characterised in terms of traffic density (Harris 1977, Graham 2003), we define *systemic cost of risk* as the cost of risk for a given level of traffic density.

1.2 *Operational Resilience*

Operational resilience is defined as the emergent property of an organisation to continue carrying out its mission after disruption within its operational limit (Caralli 2010). Operational resilience of freight railways depends on many factors. Whereas the RSR measures extrinsic incidents and intrinsic occurrences as disruption, the traffic density and value addition can be viewed as proxies for the railway mission. Since these criteria are included in the definition of systemic cost of risk we propose that one way to determine operational resilience is simply to analyse the time variance of systemic cost of risk.

1.3 *Specific rail corridors under consideration*

The analysis compares the 861 km western single-track export iron ore line (IO) and the 417 km eastern double track export coal line (Coal) with the 966 km single track general freight rated manganese export line operating a heavy haul tempo model (Mn), the 1589 km single-track Gauteng – Western Cape corridor (Capecor, also "Cape"), the 736 km Gauteng – KwaZulu Natal corridor (Natcor) and selectively the 493 km Gauteng – Mpumalanga corridor (Maputo Corridor, also "Map").

The highly specialised iron ore export line from Sishen to Saldanha port also carries a small amount of domestic iron ore to a steel plant in the port of Saldanha as well as some manganese exports. Traffic along the coal line between Ermelo yard and port Richards Bay is split roughly 70/30 between export coal and other commodities classified as general freight. Manganese is exported between Postmasburg and Port Elizabeth, which traverses the Gauteng – Western Cape corridor for a fair portion of the route before joining the Gauteng – Port Elizabeth general freight line. The two dominant general freight corridors linking the Gauteng hinterland province to KwaZulu Natal (Natcor) and Western Cape (Capecor) respectively are included in the analysis to contrast the heavy haul operations. Table 1 shows the traffic volumes.

Table 1. Rail traffic volumes in South Africa in million metric tonnes per annum (Transnet 2014 2016)

		Heavy Haul	
	General Freight	Export Coal (26 tonnes per axle)	Export Iron Ore (30 tonnes per axle)
2010/11	72.1	61.8	44.7
2011/12	73.7	62.2	46.2
2012/13	81.0	67.7	52.3
2013/14	82.6	69.2	55.9
2014/15	90.5	76.3	59.7
2015/16	84.0	72.1	58.1

2 RAILWAY OCCURRENCE DATABASE

Since 2010 the overall freight and passenger railway system remains stressed by unwanted extrinsic incidents emanating from the external environment and crossing the highly permeable system boundary into the railway system, which is further destabilized by intrinsic occurrences (Fig. 1 and Fig. 2).

Theft (65%) and vandalism (21%) dominated extrinsic incidents in 2015/16 (RSR 2016). Lopez (2001) determined that people will resort to crime if the probability of getting caught and the punishment for an offense is less than the expected payoff per offense, the cost incurred to commit the offense, and the expected payoff to perform alternative legitimate activities. Table 3 shows that extrinsic incident cost, including crime), is a relatively small component of railway occurrence cost. The compound effect of crime on cost of risk is not well understood.

Table 2. Trends in national railway occurrences for all freight and passenger rail traffic (RSR 2016)

	Intrinsic Occurrences	Extrinsic Incidents
2010/11	4 181	6 379
2011/12	4 348	5 702
2012/13	4 262	4 124
2013/14	4 587	4 703
2014/15	4632	6 222
2015/16	4251	5 520

Table 3. Railway occurrence cost for freight and passenger in South Africa in Rand million (RSR 2016)

	2013/14	2014/15	2015/16
Derailments (blue)	260.17	298.03	444.74
Collisions (green)	75.00	67.00	130.00
Train fires (yellow)	106.36	79.48	209.46
Level crossing accidents (orange)	47.16	73.32	13.48
Theft & vandalism (red)	53.00	74.00	92.00
Total	541.69	591.83	889.68

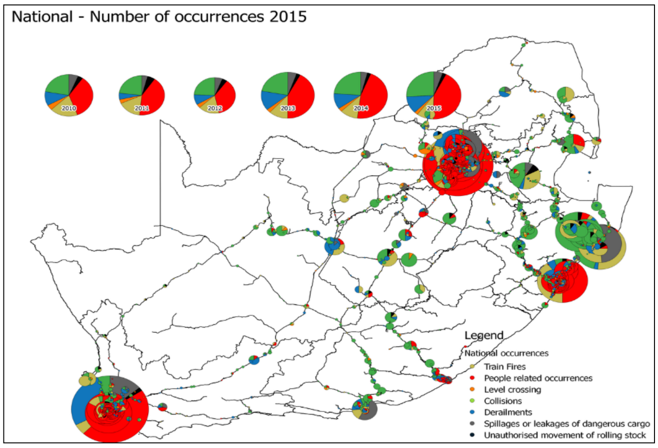

Figure 1. Relatively sized total number of intrinsic occurrences and extrinsic incidents per railway occurrence cost category for freight and passenger for 2015/16 (RSR, 2016)

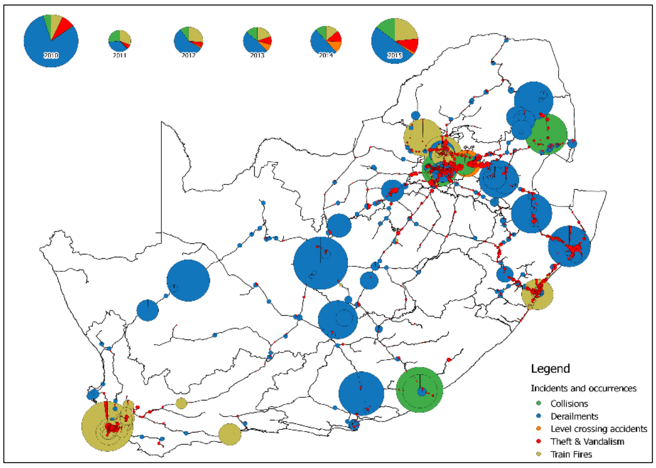

Figure 2. Relatively sized total number of intrinsic occurrences and extrinsic incidents per railway occurrence cost category for freight rail during 2015/16 (RSR, 2016)

3 GEOGRAPHICAL INFORMATION SYSTEM AND DATA VISUALIZATION

The RSR database was uploaded using open source software distributions that are very well documented and regularly updated, and supported by rich online knowledge exchange forums and resources. From a technical perspective, the PostgreSQL system coupled with PostGIS are used as the spatial relational database management system (Spatial RDBMS) optimised for storing and querying spatial geometric data; and the QGIS geographic information system (GIS) software is used to visualise processed data stored in the Spatial RDBMS. The database of extrinsic incidents and intrinsic occurrences can be visualised in the time domain (Fig. 3); in the frequency domain, which is the subject of ongoing research; or geospatially on maps (Fig. 4 to Fig. 8).

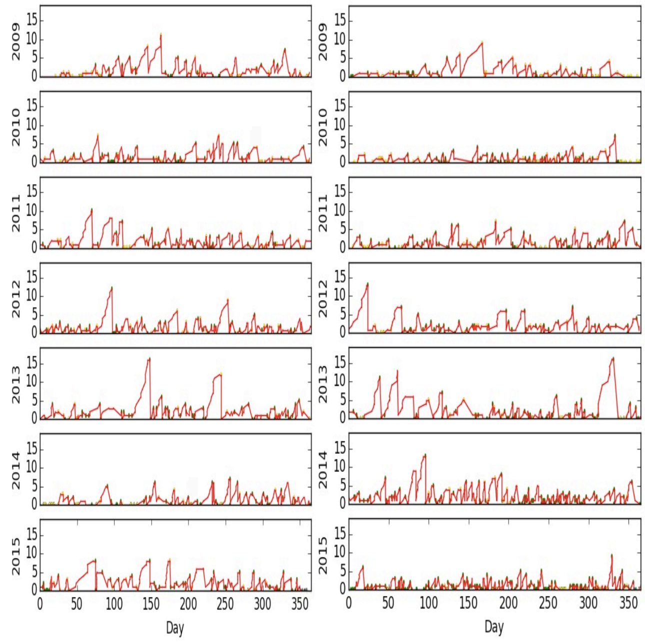

Figure 3. Instantaneous time series of extrinsic incidents (red) and intrinsic occurrences (other colours) on the Iron Ore and Coal export lines for calendar years 2009 – 2015

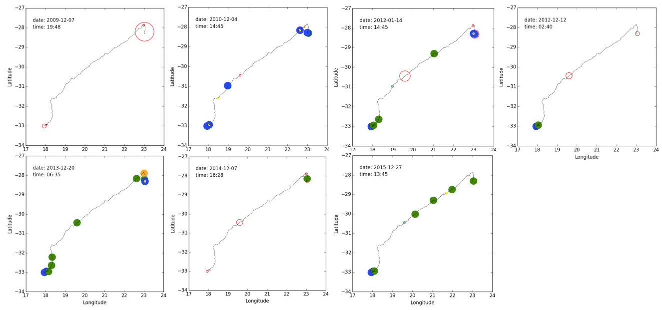

Figure 4. 2009 to 2015 annual build-up of railway occurrences relatively sized by count for the export Iron Ore line showing extrinsic incidents (hollow circles) and remnant intrinsic occurrences since the last extrinsic incident (coloured circles by type of cost)

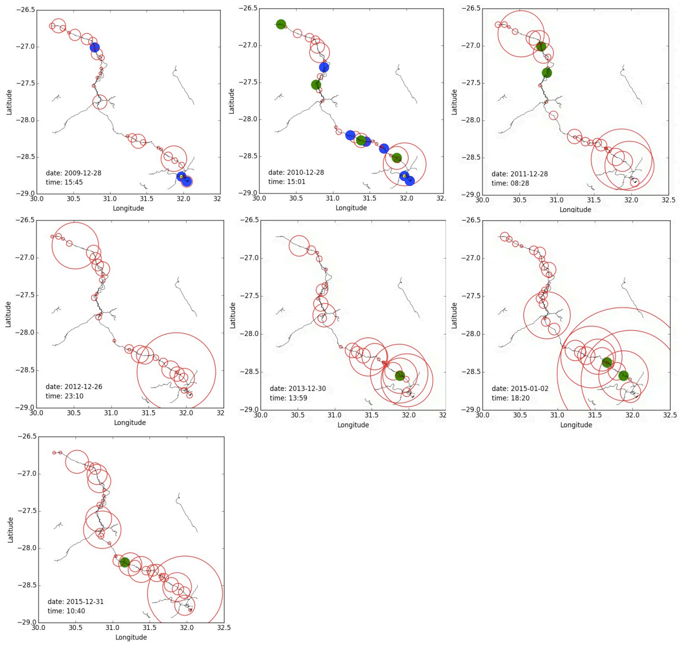

Figure 5. 2009 to 2015 annual build-up of railway occurrences relatively sized by count for the export Coal line showing extrinsic incidents (hollow circles) and remnant intrinsic occurrences since the last extrinsic incident (coloured circles by type of cost)

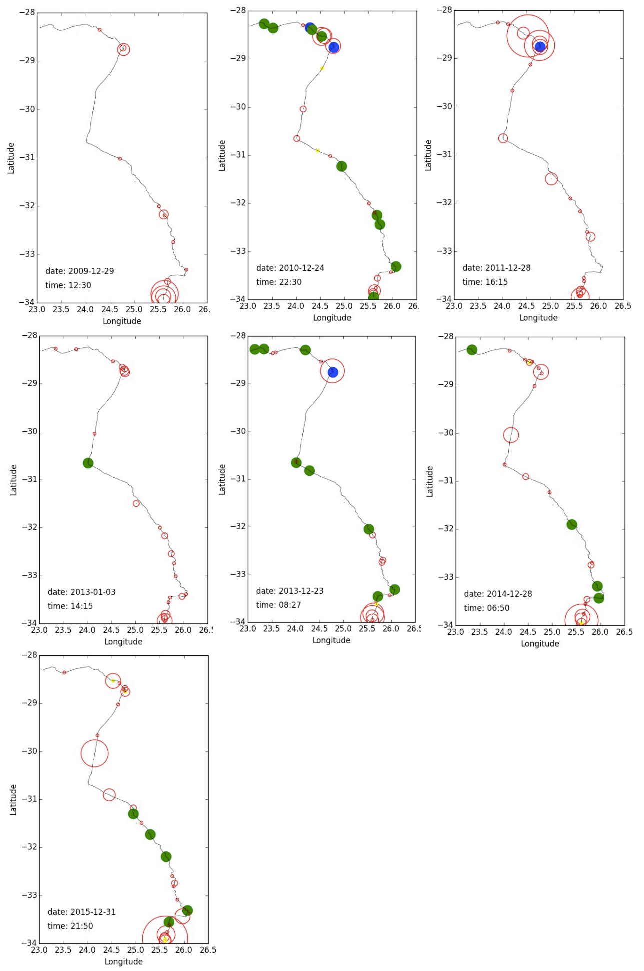

Figure 6. 2009 to 2015 annual build-up of railway occurrences relatively sized by count for the general freight export Manganese line showing extrinsic incidents (hollow circles) and remnant intrinsic occurrences since the last extrinsic incident (coloured circles by type of cost)

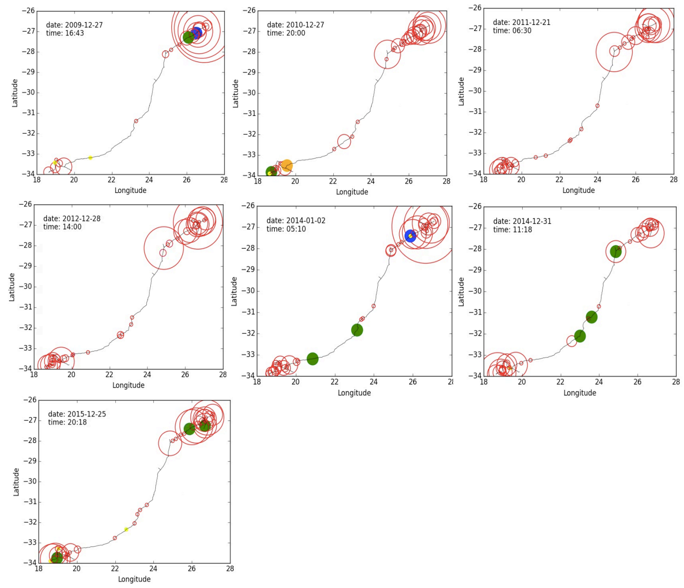

Figure 7. 2009 to 2015 annual build-up of railway occurrences relatively sized by count for the general freight Capecor showing extrinsic incidents (hollow circles) and remnant intrinsic occurrences since the last extrinsic incident (coloured circles by type of cost)

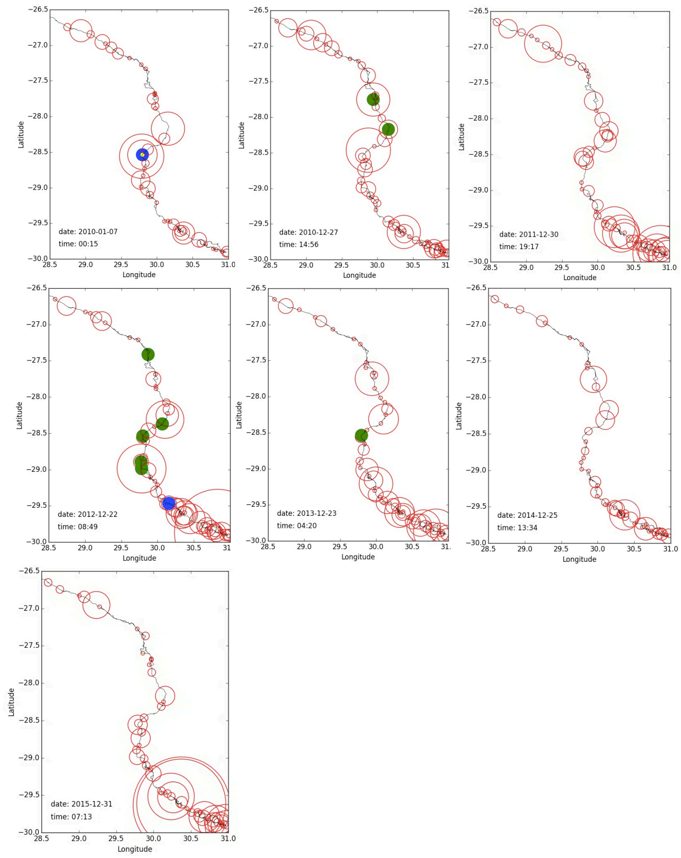

Figure 8. 2009 to 2015 annual build-up of railway occurrences relatively sized by count for the general freight Natcor showing extrinsic incidents (hollow circles) and remnant intrinsic occurrences since the last extrinsic incident (coloured circles by type of cost)

4 SYSTEMIC COST OF RISK

The annual counts of extrinsic incidents and intrinsic occurrences for the South African freight rail system over the observation period, listed in Table 4 and mapped to scale in Fig. 9, suggest a persistent level of risk in operations.

Although the percentage collisions are growing annually with high counts between Ermelo and Richards Bay, on the Natcor and on the manganese export line in 2015/16, this does not necessarily reflect the cost of systemic risk on corridors.

Table 4. Extrinsic incidents and intrinsic occurrences reported to the Railway Safety Regulator (RSR 2016)

	Extrinsic Incidents	Intrinsic Occurrences
2009/10	2 901	2 654
2010/11	2 680	2 450
2011/12	2 722	2 115
2012/13	1 985	2 004
2013/14	2 022	2 292
2014/15	2 199	2 200
2015/16	2 522	2 333
Total	17 031	16 048

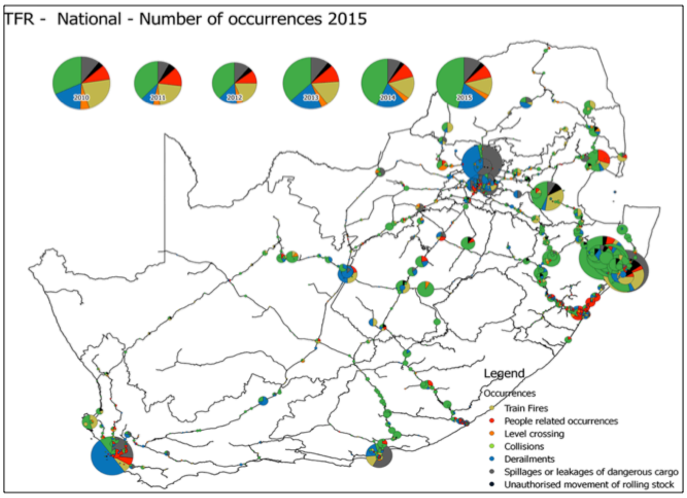

Figure 9. Total number of intrinsic occurrences and extrinsic incidents per railway occurrence cost category for freight only during 2015/16 also showing relative pie charts since 2010/11 (RSR 2016)

Fig. 10 shows the normalized occurrence cost versus the economic utility for each major corridor during 2015/16. Fig. 11 shows how this relates to systemic cost of risk.

Given the fixed cost nature of rail, we've assumed the long-term freight density for freight rail to be constant for the six–year observation period as shown in Table 5.

Table 6 lists the input data used to determine systemic cost of risk for South African corridors. All the data arranged in descending order of the six-year average. Note that although there is ordinal movement form year to year between the general freight corridors, the specialised heavy haul export coal and iron ore corridors consistently maintain the lowest systemic cost of risk.

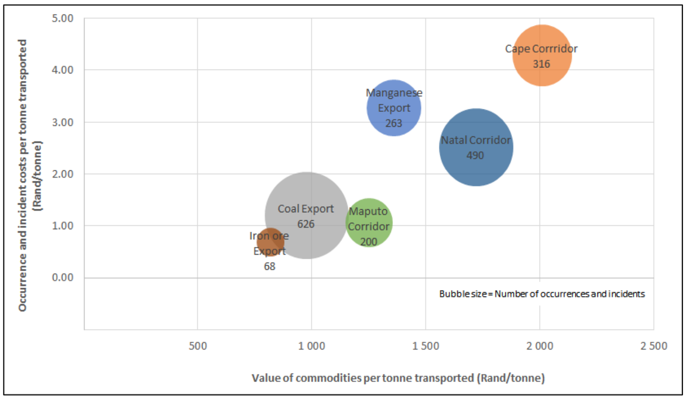

Figure 10. Railway occurrence counts and cost for the value of freight transported per major corridor 2015/16 (RSR, 2016)

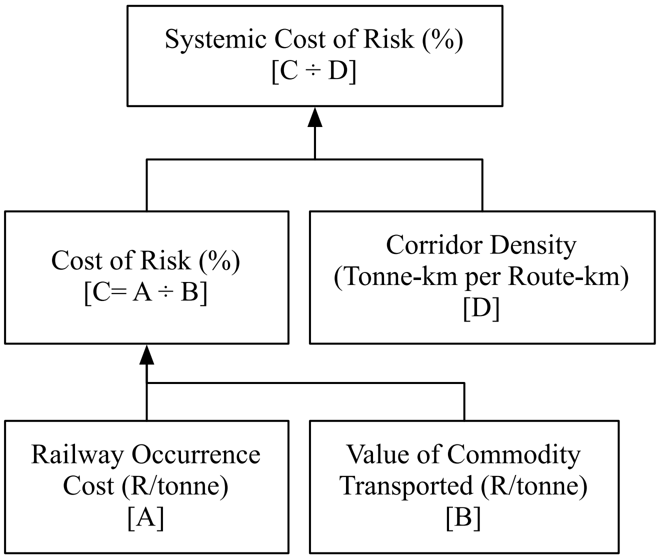

Figure 11. Systemic cost of risk

Table 5. Long term density (tonne.km per route km) penalty per corridor for freight rail in South Africa normalized to the export Iron Ore corridor (US 2010)

Corridor	Relative Density Penalty (weighting factor)
Maputo	22.11
Export Manganese	17.69
Capecor	16.73
Natcor	9.98
Export Coal	1.54
Export Iron Ore	1

Fig. 12 shows that the systemic cost of risk for the major corridors in South Africa exhibit asymptotic behaviour with freight density. Since 2010/11 the systemic cost of risk remained discernably higher for red-indicated general freight corridor activity compared to blue-indicated heavy haul corridors.

Table 6. Source data to determine systemic cost of risk in South Africa sorted in descending order by observation period average

Systemic Cost of Risk (%)						
FY	Cape	Map	Nat	Mn	Coal	IO
2010	7.663	6.633	3.677	1.557	0.327	0.212
2011	5.276	5.043	3.878	0.778	0.030	0.021
2012	7.135	2.986	7.038	1.395	0.122	0.009
2013	0.823	5.800	2.891	1.490	0.124	0.043
2014	2.583	3.940	1.918	1.430	0.064	0.044
2015	3.564	1.877	1.460	4.261	0.189	0.083
Avg.	4.507	4.380	3.477	1.818	0.142	0.069
Railway occurrence cost (Rand per metric tonne)						
FY	Nat	Cape	Map	Mn	Coal	IO
2010	4.94	4.45	4.42	0.79	2.31	1.61
2011	5.83	3.72	2.57	0.45	0.23	0.19
2012	9.75	6.77	1.33	0.87	0.80	0.07
2013	5.21	0.92	2.90	1.06	0.80	0.34
2014	3.44	2.98	2.16	1.03	0.40	0.36
2015	2.52	4.28	1.06	3.28	1.20	0.68
Avg.	5.28	3.85	2.41	1.25	0.96	0.54
Commodity value (Rand per metric tonne)						
FY	Cape	Nat	Map	Mn	Coal	IO
2010	972	1 341	1 472	897	1 085	757
2011	1 179	1 500	1 126	1 015	1 168	881
2012	1 588	1 383	982	1 109	1 018	758
2013	1 864	1 800	1 107	1 255	1 000	784
2014	1 930	1 789	1 210	1 277	972	822
2015	2 010	1 722	1 251	1 361	977	819
Av	1 591	1 589	1 191	1 152	1 037	804
Number of railway occurrences						
FY	Nat	Coal	Cape	Map	Mn	IO
2010	452	377	273	277	229	44
2011	445	384	302	258	252	48
2012	458	319	301	220	216	52
2013	457	436	271	259	263	41
2014	407	530	285	452	258	54
2015	490	626	316	200	263	68
Avg.	452	445	291	278	247	51

It is conceivable that an element of systematic cost of risk lies embedded in the data. We define *systematic cost of risk* as an artificial risk threshold programmed into the railway over many years using quasi-static conventions and imperfect policies procedures standards and guidelines (PPSGs). If so, systemic cost of risk can be reduced through technical audits that review conventions, update PPSGs, identifies value-engineering opportunities prior to recapitalisation and restructuring interventions.

When we arrange the annual systemic cost of risk per corridor in descending order, we note asymptotic behaviour of systemic cost of risk with freight density. Although the corridor order of red-marked general freight corridors vary from year to year, the heavy haul lines consistently occupy the lowest and second lowest systemic cost of risk. Furthermore the coal export corridor remains in second best position and the iron ore export corridor remains the systemic cost of risk leader.

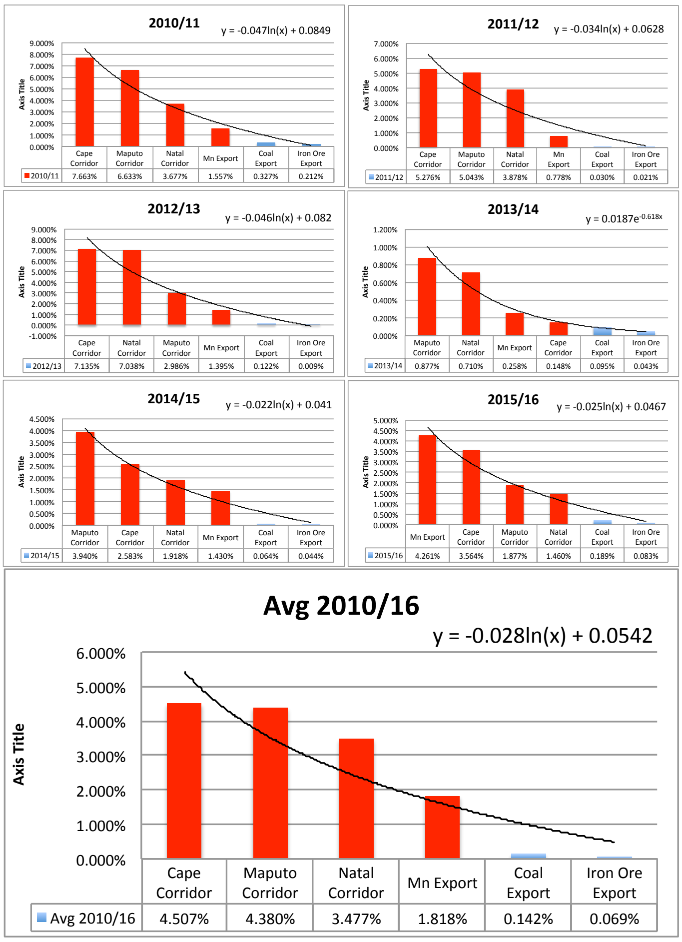

Figure 12. Systemic cost of risk for the major corridors in South Africa in asymptotic sequence

5 OPERATIONAL RESILIENCE

Operational resilience of freight railways depends on many factors. Railway operations on both the Capecor and the Manganese export corridor carry interleaving traffic, which increases operational complexity. Challenging topography on the eastern escarpment tends to concentrate intrinsic occurrences, mostly collisions, and some derailments. Corridors originating and terminating in highly populated urban areas experience high numbers of localised extrinsic incidents that could increase systemic cost of risk. It is common cause in South Africa that cable theft and vandalism of metal structures severely impact the integrity of cabled field systems. These and many other factors drive systemic cost of risk. The merits of these assertions are part of on-going research.

Whereas the RSR measures extrinsic incidents and intrinsic occurrences as disruption of the safety envelope associated with a permitted operator, the traffic density and value addition can be viewed as proxies for the railway mission. Since these criteria are included in the definition of systemic cost of risk, we propose that one way to determine operational resilience is simply to analyse the time variance of systemic cost of risk. Table 7 and Fig. 13

shows traffic volumes and systemic cost of risk for the two heavy haul lines in South Africa

Table 7. Systemic Cost of Risk and rail freight traffic volume for coal and iron ore exports from South Africa for 2010/16

	Export Coal line		Export Iron Ore line	
	Freight Volume (million tonnes)	Systemic cost of risk (%)	Freight Volume (million tonnes)	Systemic cost of risk (%)
2010/11	61.8	0.327	44.7	0.212
2011/12	62.2	0.030	46.2	0.021
2012/13	67.7	0.122	52.3	0.009
2013/14	69.2	0.124	55.9	0.043
2014/15	76.3	0.064	59.7	0.044
2015/16	72.1	0.189	58.1	0.083

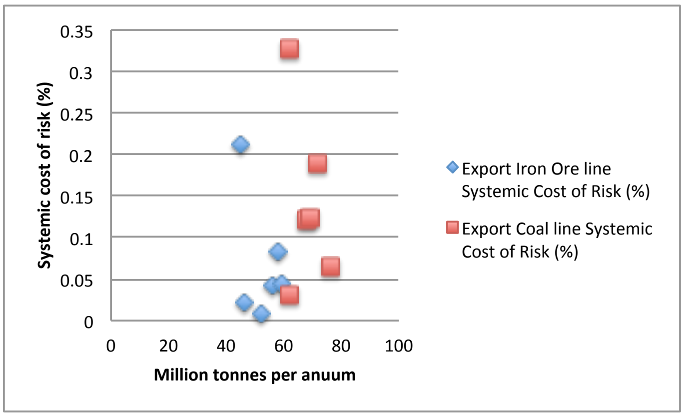

Figure 13. Systemic cost of risk for the heavy haul lines as traffic volume varied between 2010 and 2015

6 CONCLUSIONS

We can draw the following conclusions from rigorous analysis of the RSR data between calendar years 2009 and 2015. Firstly, geospatial visualization of the RSR database presents mental models to facilitate joint critical analysis of extrinsic incidents and intrinsic occurrences and testing of hypotheses. Secondly, railway occurrences remain manifold and evenly split between extrinsic incidents and intrinsic occurrences. Thirdly, the high-value/low-volume general freight corridors incur significantly more railway occurrences per unit of density than the low-value/high-volume heavy haul corridors. Fourthly, the systemic cost of risk for heavy haul lines in South Africa is substantially lower than for general freight lines. Fifthly, the systemic cost of risk is asymptotic with traffic density and can be used as a convenient indicator of operational resilience for freight railways in South Africa.

7 RECOMMENDATIONS

Further research towards improving operational resilience is required to develop a model for the relationship between extrinsic incidents and socio-economic factors; and between extrinsic incidents and intrinsic occurrences. It could also be beneficial to expand the analysis of cost of risk to include indirect costs such as opportunity costs, costs due to delays and environmental rehabilitation costs. In the interim a technical audit in concert with business interventions such as process reengineering, change management and supply chain reconfiguration could improve on the systemic cost of risk. The impact of extrinsic incidents on operational resilience could be mitigated through a revised social contract with wayside communities and focused corporate social investment.

8 ACKNOWLEDGEMENTS

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