RAPID DESK BASED STUDY:

Research Gaps in Rail Engineering and Technical aspects of High Volume Transport in Low Income Countries

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Report Summary

Main line railway transport is well known as an effective system for the movement of people and freight between cities, towns and industrial centres, while metros, light rail and tram system serve the same purpose in urban areas. Several low income countries (LICs) were served by rail based transport from the late 19th and early 20th century, although some of the railways were neglected and closed, when road transport became more widely available. In general, the routes had been built to carry export and import traffic and achieved rather limited penetration of the hinterland. Today, both LICs and the relevant funding agencies ignore the potential contribution of the different rail modes of transport towards solving some of the pressing physical communication needs in these countries and their major cities.

One reason for this lack of interest may be linked to the fact that, today, railways, metros and tramways are viewed as expensive solutions that can only be funded by relatively wealthy nations. Unfortunately, little research appears to have been conducted on how to design, build and operate affordable railways, given the specific constraints and requirements of LICs, even though many national and international bodies have invested a great deal of effort into identifying means of financing railway projects and into the political administration of railways and similar public services.

The authors of this report briefly examine the available know-how to support the design and operation of railways in LICs and determine the gaps that exist in research into railways for LICs. They have discovered that much effort has been expended in finding suitable financing and sustainable economic systems for transport in developing countries but only very limited research has been conducted on the specific technical issues peculiar to LICs. Most of the research gaps identified relate to the technical development of systems capable of providing low-cost, sustainable railways in countries with finite funds, limited technical resources and a lack of robust maintenance cultures.

In the view of the authors of this paper, the most critical gaps in the research for railways in LICs are the design of a long-term reliable and affordable types of railway track design and the development of high resilience railway control (signalling) and communications systems.

Research is also needed into ways of getting a sustainable and long term financial and operational management structure, both of which are crucial to allow success for railways in LICs.

SECTION 1

Introduction

Background

Rail transport is well known as an effective system for the movement of people and freight between cities, towns and industrial centres, while urban settings can be served effectively by trams, light rail systems and heavy metros. The provision of a well designed and reliable rail system can be a major boost to a country's economy but it is expensive to install and operate and it relies upon well-trained and motivated staff to maintain and manage the operation. If a railway system is to be effective and to fulfil its contribution to a nation's economy, the system's design and technology has to be understood first and then provided in a way that meets the topography, climate, traffic and stakeholders' requirements.

Proper assessment and research into each railway project is necessary to ensure value for money. This is especially important in low income countries (LICs). Much work has been done on proposing means of financing railway projects and on the political administration of railways and similar public services but there appear to have been only very limited research efforts to support the design, building and operation of railways that satisfy the specific requirements and constraints and of LICs.

In the present report, the authors describe the gaps that they have identified in the available research on the technology of railways for LICs.

Brief

The requirement was to undertake a rapid, desk based study to identify the key research gaps in rail engineering and technical aspects of high volume transport in LICs to inform the Department for International Development's (DFID) thinking and scoping of future work.

Structure

This gap analysis is the result of a rapid desk based study of literature (peer reviewed and grey material) to identify research gaps in rail engineering and the technical aspects of high volume rail transport infrastructures and services (passenger and freight) in LICs for both urban and rural settings.

The authors describe the methodology that was used to identify the research gaps and then discuss some general issues. This analysis is followed by specific topics that cover the research gaps currently known to the authors. There is a summary that has been added at the start of the paper in accordance with the request for a web page style summary.

Methodology

This study has been carried out with a desktop search of sources of academic papers through the University of Birmingham library plus the databases of Taylor & Francis, Routledge, Wiley, the Science Research Network, JSTOR, Elsevier, the World Bank, the African Development Bank, the Asian Development Bank, Google Scholar and the

International Union of Railways (UIC) to determine the range of railway related research related to under developed areas of the world and those countries with poor rail-based communications. This provided a rough guide as to the range of currently available research and to the areas where research was missing. An overview of the sources reviewed is provided in Table 1.

Trade Journals	Academic Journals	Conference Proceedings
Railway Gazette International	Journals of the Institution of Civil Engineers	Transport Research Board
International Railway Journal	Journals of the Institution of Mechanical Engineers	ASME/IEEE Joint Conference
Modern Railways	Journal of Rail Transport Planning & Management	American Railway Engineering and Maintenance-of-Way Association
Tramways & Urban Transit	International Journal of Rail Transportation	Institution of Railway Signal Engineers
Rail Technology Magazine	Journal of Modern Transportation	Institution of Civil Engineers
Rail Professional	IET Journals	Institution of Mechanical Engineers
Railway Age	Transport Policy	International Conference on Railway Engineering and Management
European Railway Review	Journal of Transport Geography	World Congress on Railway Research
Interface Journal	Research in Transportation Economics	Institution of Engineering & Technology
Japan Railway & Transport Review	Journal of Transport Economics and Policy	World Bank
Mass Transit	Transportation Journal	
Metro Magazine	Journal of Transport Economics and Policy	
Metro Report International	Economic and Political Weekly	
Railway Track & Structures	The World Bank Research Observer	
Railways Africa		
TDH Rail		
Track & Signal		

Table 1 Main sources of information surveyed in this study

Following on from the literature based work, we had discussions with academic colleagues and experts in the University of Birmingham Rail Research & Education Centre to confirm, as far as possible, the results of the desktop search and to expose those areas not noted in the search and the possible gaps they perceive.

It is difficult to supply evidence for research that is not available but we receive regular requests for information that gives us an insight into what is missing

In parallel, we developed a report format to comply with the required scope and form of presentation. This includes a background to the rail industry and its technology in low income countries and how the gaps in research relate to the technology.

Theme	Sub-theme	Citation
Railway Planning	Route Capacity	77
	Construction	66
	Terminal design and layout	41
	Equipment manufacturers	11
	Traffic forecasting	73
	Maintenance Planning	75
Railway Operations	Signalling and railway control	117
	Staffing	11
	Train planning	8
	Emergency management	2
	Freight	235
	Commercial management	2
Track & Formation	Route construction	20
	Formation	3
	Track types	67
	Maintenance	23
	Wheel rail interface	14
Train Control	Signalling	21
	Movement management	129
	Railway control	14
	Systems	13
Traction & Rolling Stock	Locomotives	88
	Multiple units	8
	Wagons & freight cars	20
	Maintenance	45
	Manufacture	23
Electrification	Systems	38
	Power distribution	4
	Rolling Stock	2
	Maintenance	99
	Installation	77
	SCADA	11
Total		**415**

Table 2 Main themes and sub-themes of surveyed railway research

Research by Themes

As requested, we have conducted an electronic search of our academic databases using keywords and combinations of keywords, as listed in Table 2. We found a wide disparity in the quantity, quality and relevance of what was reported in the academic papers, articles and conference contributions listed under the various keywords. There are also some papers that cover more than one subject. This is in line with our original survey.

General Issues

Standards

European and North American railways are highly developed and equally highly regulated. They follow large number of operational and engineering standards that are applied across the industry. Railways being specified for low income countries often use consultants or engineers who adopt the same standards, knowing them to be safe and proven. However, these standards, like the Technical Specifications for Interoperability (TSIs) that are being adopted in the European Union, are not always appropriate in a low income country.

What is needed is research into ways of using the European TSIs as standards for conventional interoperability in a LIC context and including the applicability of AREMA (American Railway Engineering and Maintenance-of-Way Association), European Committee for Standardization, CEN and similar standards. Although standards are very useful they must be applied carefully. Appropriateness of maintenance standards might also be a research issue. If they are too stringent, they will be ignored – they must therefore, be fit for purpose.

Technology Transfer

A number of heavy haul railways built in low income countries are specifically developed for mining operations or similar bulk transport requirements but these are often owned or financed by private companies and are managed separately from the national railway. Research needs to be done to determine if the technical expertise of such operations could be used to benefit the national railway system of the LIC where the operation is based. This would allow a form of technology transfer and training for national railway staff. It could be worth considering a wider adoption of a requirement for technology transfer when such concessions are negotiated with governments.

Infrastructure Monitoring

Railways in LICs are often routed across remote areas with poor road access. Maintenance inspections have to be carried out by rail based vehicles, often requiring trains to be delayed or cancelled. One useful area for research would be into the use of low cost aerial monitoring systems, i.e., cheap drones that could be used for the inspection of railway infrastructure. Such drones would carry out regular inspections, recording route condition in remote areas and sending this to the maintenance centre for analysis. A drone could also be used in emergency situations where poor weather is likely to cause damage to the infrastructure so that lines can be inspected without the need to send a train at slow speed along the route.

SECTION 2

Railway Construction Costs

In the UK, the cost of a new railway can be estimated to be an average of £77million per kilometre. This figure is based on a report by the (National Audit Office (NAO) on the construction of the High Speed One (HS1) route between London and the Channel Tunnel at £55m/km with £20m/km added by the authors for finance costs. Research by the authors suggests that this represents, in today's money, the same sort of investment levels for new construction in the mid-Victorian era of the 19th Century railway building boom.

Of course, our figures are based on UK circumstances, where the population is relatively dense, land is expensive and the cost of living is high compared with LICs. The UK railway costs include for a double-track main line railway, passenger equipment, high capacity energy and train control systems and stations. At the most expensive end of the scale, an underground metro system like London's Crossrail, with its large scale tunnelling costs, is costing £500m/km. There are, of course, wide variations across the world.

Railway Investment in LICs

We have prepared a list of railway investment packages in low income countries. These have been complied from published sources such as the trade journals Railway Gazette International and International Railway Journal and the website Railway-Technology.com. The list considers packages currently in progress or very recently completed.

We have filtered the reports to eliminate projects that have been started but abandoned. Often, reports have appeared that state that projects have been started, usually with a high profile member of the government concerned plus a representative of the lending country in attendance at a staged ceremony. In many of these cases, the project soon stalls and work is abandoned.

There are also a large number of plans for rail projects that have been through a feasibility study but these are either not started (usually for lack of finance), awaiting the results of further feasibility studies due to a change of scope or financial or political constraints. These have not been included in our list.

Country	Project	Dates	Cost
Afghanistan	75km line Hairatan to Mazar-i-Sharif	2010-2011	USD170m
Bangladesh	Dhaka Metro 20.1km elevated Line 6	2013-2019	¥10.477bn
Bangladesh	20 x 3-car new DMUs	2011-2013	USD58.3m
Bangladesh	Line doubling and upgrades	2012-2020	USD280m
Bangladesh	55 freight cars supplied by China	2009	375m taka
Bangladesh	Joydepur and Kamlapur dual gauging	2006-7	3.3bn taka
Cambodia	405km North-South Rly	2013-2017	USD1.1bn
Cambodia	600km line rehabilitation	2007-2013	USD141m

Country	Project	Dates	Cost
Ethopia	447km of new railway being constructed between Awash and Woldia.	2012- 2015	USD1.7bn
Ethopia	268.2km of new railway from Mekelle Woldya to Hara Gebeya	2012-2015	USD1.5bn
Ghana	24km Accra-Tema suburban line rebuilding	2010	USD32.5m
Indonesia	42km Badung suburban upgrading	2013-2016	USD175m
Indonesia	Trans-Java (Pantura) line doubling for 425km	2011-2014	USD1.1bn
Indonesia	15.7km Jakarta metro	2013-2017	¥125bn
Indonesia	130km Kalimantan Coal Line	2009-2014	US$1.2bn
Indonesia	30 used Japanese EMU trains	2013	N/A
Kazakhstan	8.5km Line One of the Almaty Metro	2001-2011	USD1.1bn
Kenya/Rwanda	2937 km new railway between Kampala & Kigali	2013-?	USD13.5bn
Laos	220km new railway PPP for 50 years	2012-2062	USD5bn
Myanma	15 units of used Japanese DMU trains	2012	N/A
Myanma	20 DE locos from China	2007-2009	N/A
Nigeria	Abuja-Kaduna (186km) re-gauging & modernisation	2011-2014	USD 874m
Nigeria	Lagos Metro Blue Line (27km)	2008-2014	USD1.2bn
Philippines	Manila Lines 1 & 2 extensions loan	2013-?	USD436·2m
Philippines	22km Manila new Line 7	2010-?	USD1.12bn
Philippines	60km main line rehabilitation	2007	USD50m
Sri Lanka	Matara-Kataragama new railway (114.5k)	2010-2015	USD366m
Uganda + Keyna	Rift Valley Rly train control	2013-2015	USD9.3m
Vietnam	Ho Chi Minh Metro new Line 1, 20km	2008-2017	47tr Dong
Vietnam	Hanoi Metro 12.5km new pilot line	2007-2014	€500m est.
Vietnam	Resignalling main lines	2011-2015	USD50m
Vietnam	Railway modernisation and new lines	2012-2015	USD9.5bn
Zambia	900km rehabilitation & double tracking	2013-2016	USD120m
Zambia	200km of rehabilitation	2001-2014	N/a
Zambia	90 x 50t freight wagons	2010	36m yuan

Table 3 Major Rail Investment in Low Income Countries

In Table 3, we have shown various railway projects in African and Asian states with the time of their implementation and the published project value. Currency is in the reported values of the time of publication. It should be noted that there is a wide divergence between timescales as related to line length, project scope and cost. Usually, this is as a result of a number of factors, either singly or in combination, including false starts, local and international financing processes, political changes, changes on scope and poor project management. For these reasons, any attempt to correlate time, money or project scope is fraught with uncertainty.

Some technical difficulties remain with upgrading railways and providing cross-border links. These are caused by the various gauges used in Asia and Africa. Often, new cross border routes are made difficult to implement without changing the gauge of one side or the other or introducing dual gauge tracks. Both options add cost to the project. Gauge differences also restrict the use of second-hand rolling stock, a popular method for upgrading equipment. In the countries noted in our table, the range of gauges is 1000mm, 1067mm, 1435mm, 1520mm and 1676mm.

Anecdotally, it is possible to state that there has been a worldwide increase in railway investment. This seems to be reflected in our table, with a higher number of projects reported in more recent times, although this may be due, in part, to improvements in communications and transparency.

The increase in projects is likely to have been due to a number of causes, including a rise in environmental awareness, increases in fuel prices and carbon taxation, rises in road traffic congestion, more rail privatisation in its various forms, increases in world freight movement and improvements in political attitudes to railways with a better realisation of their economic value.

Case Study 1 - Philippines

Common issues in LIC rail investment projects that fail or are seriously delayed relate to such issues as international loan misunderstandings, project implementation difficulties, partisan politics and corruption. In this brief case study of the project to build a new 80km railway between the capital of the Philippines, Manila and the Clark Air Force Base, we find that it began with a USD400million loan agreed between the government and the China Import-Export Bank in 2004.

When work started, there were some difficulties with alignment and later there were some accusations in the Manila press that the company doing the construction work was incompetent. The project suffered from a number of scope changes and delays that pushed up the costs so that, in 2008, work was suspended. Work restarted in 2009 but was suspended again in 2011 when a new government decided to investigate claims that there were irregularities in the original Chinese contract. Those experienced in the Asia business scene will doubtless surmise that there has been some form of what the west would describe as corruption in the deal.

Up to this time, no more work has been done and the project has become embroiled in political controversy with a proposal to incorporate the route into a new high speed rail link between the existing Manila International Airport and a new, expanded airport at Clark.

Case Study 2 - Zambia

The current fashion for PPP (Public Private Partnerships) contracts and concession management of state owned railways is related to the desire to reduce state owned debt burdens and it appears in plans for LICs as much as in more affluent countries. However, there are elements of risk for concessionaires as shown in the example of Zambia.

In 2003, operation of the Zambian state railways were allocated to a company known as Railway Systems of Zambia Ltd. Things didn’t go very well and in 2008, it was alleged by the government that the railway company had failed to keep the line’s equipment infrastructure and rolling stock in good enough condition to provide a safe and reliable service. They threatened to revoke the concession (RGI 2008). However, the government owed the concessionaire USD40m and a deal was reached to allow the concession to continue.

Unfortunately, the cycle of decline and deterioration continued and, in 2012, the government claimed that this "had led to deterioration of the state-owned assets, an 'unacceptable' level of derailments and poor safety, including loss of life and property." (RGI 2012). This time the concession was withdrawn and operation of the routes taken over by the government.

It is worthy of note also that a project to rehabilitate a 200km section of the railways in Zambia was started in 2001 but is not yet complete.

Another concession problem arose in 2009, this time in Tanzania, when RITES, the Indian railways consultancy operation pulled out of a concession with the government after only two years. The reason offered at the time as an explanation was non-payment of fees.

Urban Railways

There are a number of cities in low income countries that have the potential to improve mobility by installing or developing passenger rail networks. Some have already started this process. In Table 4 (below), we have compiled a list of the cities in LICs of Asia and sub-Saharan Africa that have a population of over 2 million, together with population densities and the status of the urban rail system, if provided.

Rank	Country	Urban Area	2013 Population Estimate	Land Area (sq/km)	Density (pop/sq/km)	Urban Rail System Status
2	Indonesia	Jakarta (Jabotabek)	26,746,000	2,784	9,600	Construction started
6	Philippines	Manila	21,241,000	1,437	14,800	Multi line light metro system in use.
20	Bangladesh	Dhaka	14,399,000	324	44,500	Construction started
25	Nigeria	Lagos	12,090,000	907	13,300	Construction started
31	Congo (Dem. Rep.)	Kinshasa	9,387,000	583	16,100	Suburban railway in use.
37	Viet Nam	Ho Chi Minh City	8,764,000	1,269	6,900	Construction started
64	Angola	Luanda	5,425,000	767	7,100	Suburban railway in use.
70	Sudan	Khartoum	4,919,000	932	5,300	None
74	Indonesia	Bandung	4,764,000	427	11,100	None
76	Indonesia	Surabaya	4,703,000	673	7,000	None
77	Myanmar	Yangon	4,620,000	350	13,200	Suburban railway in use.
79	Ivory Coast	Abidjan	4,603,000	324	14,200	None
84	Kenya	Nairobi	4,457,000	557	8,000	Suburban railway in use.
95	Ghana	Accra	3,933,000	945	4,200	None

Rank	Country	Urban Area	2013 Population Estimate	Land Area (sq/km)	Density (pop/sq/km)	Urban Rail System Status
104	Tanzania	Dar es Salaam	3,723,000	570	6,500	None
105	Nigeria	Kano	3,636,000	251	14,500	None
113	Afghanistan	Kabul	3,476,000	259	13,400	None
125	Senegal	Dakar	3,270,000	194	16,800	None
129	Ethiopia	Addis Abeba	3,226,000	389	8,300	None
133	Nigeria	Ibadan	3,180,000	389	8,200	None
138	Bangladesh	Chittagong	3,073,000	111	27,600	Suburban railway in use from 2013.
143	Ghana	Kumasi	3,031,000	337	9,000	None
159	Mozambiqu e	Maputo	2,691,000	414	6,500	None
162	Cameroon	Douala	2,612,000	205	12,800	None
166	Cameroon	Yaounde	2,587,000	231	11,200	None
169	Viet Nam	Hanoi	2,533,000	285	8,900	Construction started
176	Philippines	Cebu	2,463,000	207	11,900	None
183	Nigeria	Abuja	2,360,000	225	10,500	Construction started
186	Uzbekistan	Tashkent	2,316,000	531	4,400	System in use.
196	Indonesia	Medan	2,250,000	246	9,100	None
202	Burkina Faso	Ouagadougo u	2,193,000	350	6,300	None
202	Mali	Bamako	2,193,000	311	7,100	None
205	Sri Lanka	Colombo	2,177,000	223	9,800	Suburban railway in use.
215	Azerbaijan	Baku	2,112,000	298	7,100	System in use.
218	Madagascar	Antananarivo	2,075,000	220	9,400	None
224	Nigeria	Port Harcourt	2,002,000	158	12,700	Construction started

Table 4 Urban Rail in Cities of Low Income Countries of Asia & Africa (Demographia.com and Urban rail.net)

Table 4 lists 36 low income cities in Asia and Africa that have a population of over 2 million. Of these cities, 21 (58%) have no urban or suburban railway system. Almost all movement is by road transport. On these 21 cities only 5 are in Asia. The remainder (76%) are in Africa, indicating that the need for urban transport is most urgent there.

SECTION 3

Specific Research Gaps

Track

The track is a fundamental part of the railway infrastructure and represents the primary distinction between this form of land transportation and all others in that it provides a fixed guidance system. The track is the steering base for the train using the steel wheel running on a steel rail. Good track is essential for the safety and stability of the train but it is vulnerable to a wide range of external factors such as:

- Flooding;
- Ground movement or subsidence;
- Incursions of vegetation or sand;
- Infestation by wildlife and insects;
- Extremes of rainfall, heat and cold;
- Ice and snow;
- Poor maintenance;
- Theft.

Any one of these factors can cause a train to derail or can force a stoppage of movement because of the risk of derailment. In low income countries, many of these issues are commonplace and they severely effect operations. Whilst there is a large body of research available on track systems, most of it relates to mature, high volume or high speed railways in developed countries and also to bulk volume track manufacturing systems. There is a research gap in respect of low cost, modular, slab track systems that can be repaired / adjusted quickly after natural catastrophes and that is easily constructed with relatively poor quality materials. Embedded slab track reduces the risk of theft. Classical slab track has many expensive components that can be stolen. Also, slab track is easy to walk or motorcycle along for inspection purposes.

Research is required to find low cost track systems designed to allow extreme weather conditions such as flash floods to drain effectively and safely and to be capable of withstanding extremes of temperature. Low maintenance and secure rail fastening systems must be incorporated.

Another gap in research appears to be in respect of rapid track replacement or repair systems following formation damage. Such systems could be used to replace existing track and its formation as part of a line renewal project.

Infrastructure Sequencing

A railway is a complex system that involves a wide range of engineering disciplines and skills and which requires a sound operational and management structure if it to function effectively and if it is to provide the economic and social benefits expected of a utility that involves considerable public investment and support. It is therefore essential that external systems are in place to secure the continuing operation of the railway. Such systems include a functioning communications network, reliable water supplies and electrical power supplies to depots, stations, workshops, freight terminals and control centres.

The securing of essential support services for the railway is an obvious requirement but it is generally accepted that the failure of such systems is often a cause for concern in low income countries. There needs to be a full understanding of the effects of the failure of railway support systems and the resulting economic loss to the operation and the possible benefits for railways in LICs providing their own support systems or bringing such support systems into a robust railway management structure.

The provision of secure infrastructure support is an essential part of the railway system. It follows, therefore, that before the railway can be built or operated, the performance capabilities of the support infrastructure must be understood and provided for in any plan for a railway. This is one of the first and most essential parts of the sequence of railway design and construction and should be incorporated into the programme for any railway rehabilitation or new construction projects. Research is required to models to evaluate the business case for the provision of specialist support systems for railways in LICs.

Infrastructure Formation

Many low income countries suffer from extremes of climate where high levels of rainfall or other severe climatic conditions can damage railway infrastructure, particularly the formation supporting the track. There is a lack of research and development for new systems that will provide a resilient railway formation construction system or that can provide rapid repair systems for existing formations in hostile climates. The development of such systems would greatly enhance the reliability of railways in LICs.

Research is also needed into the availability of advanced but lower cost geotechnical systems to create stable formation conditions under difficult climatic conditions.

Electrification

Some of the more heavily used railways would benefit from electrification. Which systems are in this category needs to be evaluated through research into traffic levels, possible system expansions and opportunities for bulk freight operations in LICs.

Although the cost of installation can be high, this could be reduced with suitable research on and development of systems that are appropriate for the speed of operation and that are highly reliable. Research is also required into the use of local hydro-power generation to drive electric trains using lower cost but robust electrification schemes.

Railway Control (Signalling)

An essential part of the railway system is train control or signalling. It is necessary to keep trains a safe distance apart to prevent collisions but it has to balance this with route capacity requirements. Many railways in LICs operate over single lines that carry traffic in both directions. Train control has to be safely managed in order to avoid collisions but many of these lines operate in remote areas with low or no availability of electrical supplies and poor communications links. There is a research gap in respect of low cost control systems that require no cabling nor into the provision of autonomous turnouts at passing places and junctions. Such turnouts could, perhaps, be operated by mobile telephones.

There is also no research known to the authors on low cost train control systems that would be suitable for railways in urban areas of low income countries. Such “mass transit” train control systems would also require minimum equipment on the ground and little or no cabling. This reduces the need for maintenance at track level and reduces the risk of the theft of the equipment.

An area that needs more research is that covering the specification of railway control systems for countries with low incomes. Whilst these countries often aspire to high technology solutions using developed technology such as the European Train Control System, these systems may not be appropriate in a country with little technical expertise in the operation and maintenance of such equipment. As a result, the availability of the system falls rapidly and the reliability and safety of the railway deteriorates.

Often the purchase of such equipment is encouraged by the funders and suppliers of the system without regard to the long term viability of such solutions in a low technology culture. Research is needed to determine the realistic sustainability of modern railway control systems in LICs and to find appropriate solutions that consider the immediate needs and which can present a long term strategy based on development of those immediate needs into more sophisticated systems.

Rolling Stock

A common sight in low income countries is lines of rusting locomotives, coaches and wagons that have been abandoned by the railway as unserviceable because of the lack of spare parts or the lack of facilities to repair them. Many internationally funded refurbishment projects have, over the years, concentrated on rebuilding such rolling stock or replacing vehicles with new or refurbished second-hand equipment. Such equipment is usually of a standard design that requires the same maintenance and repair facilities that are available in developed countries with a mature and effective railway engineering capability. This may be a reasonable approach from a cost point of view but it is likely that, in a low income environment, the cycle of neglect will repeat itself as spare parts become rarer for the ageing machines. Refurbished or second-hand equipment will also perpetuate low efficiency traction systems and will still require regular maintenance by skilled technicians.

To break the cycle of failure and neglect, a new approach to rolling stock design for low income countries is required. New research is needed to develop sustainable, simple maintenance (where not necessary to have high tech equipment or complex facilities) railway rolling stock with long life capability.

Traditionally, railway rolling stock is expected to have a life of 30-35 years. Such life spans are based on the cost of the initial investment and its depreciation over time but some railways have, with careful husbandry of their assets, got far longer life from its rolling stock. Even in an intense metro operation like London, a new fleet of trains has recently replaced a stock that lasted 50 years in regular urban service. However, because of the increased pace of technical development, the trend in recent years has been to design rolling stock that has a short life so that it can be replaced with new, more efficient, environmentally friendly equipment as soon as the new technology becomes available. This is not likely to be appropriate for railways in low income countries.

In respect of rolling stock design for LICs, research and development is needed to produce easily repairable, long-life trains capable of sustainable operation in hostile environments. Such designs might have to incorporate new materials and systems that require minimum attention and little maintenance intervention over long periods. Such equipment would include locomotives, multiple unit passenger trains passenger coaches and freight wagons. It must be understood that low income should not mean low competence. Even basic trains benefit from properly scheduled maintenance.

It appears that there is also a research gap in respect of the use of main-frame independent networks of low-cost data terminals that support effective maintenance. The low cost computers developed for LICs and the growing mobile telephone networks should be harnessed but big SAP style applications are prohibitively expensive.

Urban Systems

Some low income countries have rail based urban transport systems like India, South Africa, Egypt, Philippines, Indonesia and Peru. They perform with varying degree of success. Urban rail systems tend to be expensive to build and maintain and often, the impetus to operate and maintain them effectively is gradually lost once the original installation is complete. However, high capacity urban rail systems can increase urban mobility, create development, generate investment and provide secure employment. They can also reduce traffic congestion and make more effective use of transportation energy.

Many other LICs do not have them. The cost of building an urban railway could be kept low by research and development into suitable technology and construction so that the project can be designed according to the local resources and needs.

There are various types of urban rail systems:

- People movers of the type used between airport terminals – usually built on elevated structures;
- Light rail systems, like those in various UK cities, mostly at grade. Can be segregated or mixed with road traffic;
- Light metro systems, like the STAR system in Kuala Lumpur and the Manila Metro, where the lines are mostly on elevated structures;
- Heavy metro systems, with central areas of routes underground or elevated, as seen in many large cities, like London, New York, Hong Kong.

Elevated, at grade and underground construction is available and systems can be designed to operate in segregated rights of way or integrated with road traffic. All types of construction can and have been used on a single route, as the circumstances require. As a very rough guide, an LIC city with 2million inhabitants should be able to afford a tram or light rail system, a city with 4million, should be able to afford a suburban rail or light metro system, and a city with 8million or more a full metro system.

A country like Turkey has a record of building cheap systems quickly. Light metro systems have been built in Istanbul, Adana, Izmir and Eskisehir – good examples of what can be done and it would be useful to study these projects in detail.

Assessment and Implementation Methodology

Some equipment, like rolling stock and train control systems, are purchased in low income countries on the basis of the source of the line of credit or aid available rather than what is best for the railway (Dheerasinghe, 1993). Such purchasing is unlikely to offer a sustainable solution to the particular requirements of the railway in the LIC.

Our review suggests that there is a gap in the research covering national and local systems of assessment and implementation for railway engineering projects in LICs. In its absence, there have been instances of projects that have failed to deliver their potential either because they were not suited to the environment in which they were developed or their implementation was incorrectly structured and managed. Such research would enable models to be created to enable a formal assessment and implementation methodology to be adopted for railway projects in LICs. The objective would be to allow a consistent and viable methodology for stakeholders and railway management in LICs when assessing and implementing projects. Such models should incorporate energy, maintenance, operational and life cycle structures.

Finance for Operational Support

There is a wide range of research available in respect of finance for renewing or constructing transport systems and other public utilities in low income countries. Much of this relates to issues surrounding the inefficiencies of government funded of managed projects and in recent years, in attempts to overcome the perceived inefficiencies of public financial management, governments and lending authorities have turned to the private commercial sector for financing. In many cases, government owned utilities have been sold to the private sector, usually at very attractive prices in order to attract purchasers who may have to spend a lot of money restructuring the organisation to make it into a profitable business.

Telecommunications, power supply and airlines are all sectors that governments have sold into private ownership and which have eventually become profitable. Railways are more difficult to sell since they have high infrastructure and maintenance costs and the income from operations is subject to severe competition, usually because railways are subject to government assisted competition from road transportation. Railways rarely make sufficient income to pay operating costs, let alone repay loans or update infrastructure.

Some progress has been made in "converting" publicly owned railway companies to private ownership but only by offering inducements, sovereign guarantees and/or financial subsidies to the new owners. This is because the numbers simply do not stack up when it comes to return on investment. In fact, as already mentioned, they rarely add up when it comes to just the cost of day-to-day operations compared with the money taken at the farebox.

Railways Making A Profit?

There is often talk of railways making a profit. In reality, this is often a reference to a railway that takes more fare revenue than it spends on operating costs. The value of the infrastructure is generally ignored, and interest payments, repayment of loans and future renewals are forgotten. A railway management company may choose to ignore renewals too, knowing that the government will be too afraid politically to let the system collapse for want of new trains or rebuilt track. Even so, in spite of removing the renewal and financing costs of the railway, few railways, even in developed countries, are able to cover all their operating costs from farebox or freight revenue.

In respect of long distance, high volume, freight haulage, distance provides a market that is best served by railways. In North America in particular, long distance freight haulage is profitable for the companies that operate in this field and this model is repeated in other countries where there are long distances between freight centres.

Where the research gap appears is in the long term appreciation of the current systems of financial management of railways and their effects on the maintenance and renewal cycles. This is especially evident in respect of long life assets like rolling stock, maintenance machines, structures and buildings. The lack of financial support for day-to-day maintenance after the renewal project in the low income country’s railway has been completed is often the cause of a rapid decline in performance and reliability. If a project is to fulfil its potential and meet its financial and economic goals, post-project support is essential, particularly in low income countries. In the authors’ view, more research needs to be done in this area.

SECTION 4

Research Issues

Expansion of Existing Research

There are a number of areas where research is being carried out in or on behalf of developed countries that could be applied to LICs. One such is the Mainline project of the International Union of Railways (UIC, 2013). This project is examining the following:

- The application of new technologies to extend the life of elderly infrastructure;
- To improve degradation and structural models to develop more realistic life cycle cost and safety models;
- The investigation of new construction methods for the replacement of obsolete infrastructure;
- To investigate monitoring techniques to complement or replace existing examination techniques;
- The development of management tools to assess whole life environmental and economic impact of new projects.

This scope is primarily directed at European railways but additional research to determine how the work could be widened towards LICs would be valuable.

Another UIC project is related to research into protection of equipment from theft. This is known as Protectrail. The PROTECTRAIL objective is to provide a viable integrated set of railway security solutions. According to the UIC (2010), the areas covered include:

- protection of signal and power distribution systems
- track clearance
- clearance of trains before and after daily use
- staff clearance
- passengers and luggage
- freight
- tracking and monitoring of rolling stock carrying dangerous goods
- protection of communication and information systems
- stations, buildings and infrastructure protection

The work is almost complete and it would be beneficial to review the results to see if any of them might be suitable for adoption in low income countries.

There is a wide range of detailed engineering studies relating to the railway industry but few of these focus on railways in low income countries. Most are related to existing systems in mature, middle or high income countries or cities with an established and sound financial base and a fully functioning operations and engineering management. A full review of existing research on railway technology needs to be carried out to determine what could be adapted or implemented on suitable railways in low income countries.

Priorities for Research

In assessing priorities for research, we offer the following list

1. In depth assessment of rail engineering research already carried out for low income countries;
2. Sources of funding for research into rail engineering for low income countries;
3. Affordable & maintainable track with low resource use;
4. Maintainability for Rolling stock;
5. Railway control systems with minimum infrastructure and on-board hardware – mobile phone technology – using an ‘app’;
6. Electrification equipment that is appropriate for the speed of operations;
7. Research into appropriate high technology – absolute core is HT but rest can be maintained simply.

Research Funding

In general, there is relatively limited funding available for railway research, outside the European Union. Apart from the UIC projects mentioned above though, there is some finance available from the European Commission Funding Programme. This is managed through CORDIS (Community Research and Development Information Service). They are currently funding their 7^{th} Programme, known as FP7. There are currently 25 railway research projects, none of which relate directly to low income countries. Most are technical and operational.

Most international funding for railways relates to specific projects – mostly new routes, re-habilitation projects or technical advice for operators. Funding for projects is usually through development banks. Research funding tends to come from within the industry for specific issues like the wheel/rail interface, new communications systems or in response to public concerns like level crossing safety. Most non-corporate research in the UK is funded through the Rail Safety & Standards Board (RSSB).

Further Research

A brief survey of this type cannot, on its own, cover all the likely research gaps that exist in the field of rail transportation technology in low income countries but, as far as we are able to determine in this brief survey, there is, in general, little research specifically related to rail technology for LICs. Further work is required to determine the extent of existing management and technical research and how it might relate to potential benefits for low income countries.

SECTION 5

Conclusions

Findings

Within the limitations of this rapid, desk based study, the authors of this report have found that there is a wide range of detailed engineering studies relating to the railway industry but few of these focus on railways in low income countries (LICs). Most are related to existing systems in mature, middle or high income countries or cities with an established and sound financial base and fully functioning operations and engineering management.

The authors have discovered that much effort has been expended in finding suitable financing and sustainable economic systems for transport in developing countries but only very limited research has been conducted on the specific technical issues peculiar to LICs.

The research suggests that most LICs are led by politicians who have little or no understanding of railway costs and benefits nor of their potential value to their country's economy. However, advice is often offered that railways are good and should be adopted, and this leads to many schemes reaching the feasibility stage and even starting construction, often with foreign aid. However, the limited financial resources of LICs and the political uncertainty often leads to the collapse of schemes, abandonment of work or withdrawal of funds.

In the authors' views, there are critical gaps in the research for railways in LICs in two main areas – management and engineering. In the former case, ways to obtain stable, long term management and a continuous funding regime; in the latter case, long-term, reliable and affordable railway track and the development of high resilience railway control (signalling) and communications systems. These issues affect both national and urban railway systems.

Recommendations

A full and detailed review of existing research on railway technology needs to be carried out to determine what could be adapted or implemented on suitable railways in low income countries.

Research is needed into ways of getting a sustainable and long term financial and operational management structure, both of which are crucial to allow success for railways in LICs.

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