MODELS DEVELOPING TO SUPPORT THE RAIL TRANSPORT STRATEGIC MANAGEMENT

PhD Thesis Booklet

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Introduction

Rail strategic management is related to the survival and growth of the sector, from time standpoint is the continued existence in the future. In a complex, modern, dynamic, competitive environments, characterised by economic, social, cultural and technological changes strategic management often struggles to keep up with unpredictable changes, but with support tools, it is well prepared for the ripples. Technology advancements have seen rail make a comeback in developed countries and its significance is indeed highlighted in the strategic document adopted by European commission entitled “Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System” [1]

On the other hand, the Sub Saharan Africa railway network, even after starting operations at almost the same time with the rest of the world, it has experienced maintenance neglection and upgrading which has led to its continued decline [2]–[5]. The rail having been established to serve colonial interests, left little room for trade between African countries and is, in fact, incapable of easing both cargo and passenger traffic in African cities. This thesis draws inspiration from African Union 2063 strategy [6], where one of the flagship projects is Integrated High-Speed Train Network which aims at connecting all African capitals and commercial centres’ to facilitate passengers’ and service movement across the continent.

It develops a series of tools for supporting the policy-makers of developing economies with stagnated rail system in making more explicit effects of technological developments on future strategic management. The following tasks have been executed: Developed a methodology to analyse the total impact in transportation and adapted to the railway system. Developed an understandable and easily useable forecasting methodology for demand prediction in the transportation system. Defined the interrelationship between railway transport and economic cycles. Analysed and recommended energy-saving strategies applicable to developing countries such as Kenya.

Methodology

This thesis used a mixed-methods approach to formulate the models among them, transport demand, forecast & innovation adoption methods, hierarchical and analogy methods with the aid of MatLab and Excel programs. It was found that the very developed countries practice cannot be applied directly to the developing countries like Kenya and the sensitive indicators
that respond to the developing countries differently from developed countries have been identified.

Models developing

The interrelationship between rail transport and economic cycles

This thesis has investigated the role of rail transportation in economic development. Especially tried to identify the cycles caused by business cycles in the sector. The business cycles are dated by the use of complex approach based actually on the economic activities of more than on one or two important economic indicators, not only based on GDP (gross domestic product) and GDI (gross domestic indicator) but also using a range of other indicators characterising the (domestic) economy. [7], [8]. Principally NBER (National Bureau of Economic Research) evaluates the significant decline in economic activity defined by monthly indicators. Unfortunately, such complex approach cannot be applied to rail transport because of the limited historical data. The most used transport indicators are the volumes (tons or number of passengers) and productivity or works done (ton-km or passenger-km). Even such data are available only as yearly measured information.

The analogy in the changes of the economic developments measured by the GDP, as shown in Figure 1 (a gap between the well and less developed countries), allows using the historical data of well-developed countries.

![Figure 1. Real economy developments of selected countries (left) and curves “dated back” for Hungary and Poland (right) (used input source: WDI)](image-url)
The same analogy for developing countries is applied see Figure 2 ‘dating back’ economic developments for selected Sub-Sahara countries showing 50 years lag. There were studied statistical characteristics (as correlation data) Table 1, the approximation of the available time series by Matlab and excel software, evaluation of the analogy in different comparison studies, and applying the logic reasoning Figure 3.

Table 1. Correlation between the economy and Railway transport indicators

<table>
<thead>
<tr>
<th>Country</th>
<th>Volume of Goods transported (t-km)</th>
<th>Passenger carried (pass-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>-0.19499</td>
<td>-0.37425</td>
</tr>
<tr>
<td>Tanzania</td>
<td>-0.46571</td>
<td>-0.71696</td>
</tr>
<tr>
<td>India</td>
<td>0.95861</td>
<td>0.98576</td>
</tr>
<tr>
<td>China</td>
<td>0.78665</td>
<td>0.841281</td>
</tr>
<tr>
<td>Japan</td>
<td>0.32059</td>
<td>0.696024</td>
</tr>
<tr>
<td>France</td>
<td>0.88334</td>
<td>0.902141</td>
</tr>
<tr>
<td>Russia</td>
<td>0.561092</td>
<td>0.32653</td>
</tr>
<tr>
<td>United States</td>
<td>0.951302</td>
<td>0.80315</td>
</tr>
<tr>
<td>Germany</td>
<td>0.421429</td>
<td>0.72345</td>
</tr>
<tr>
<td>Italy</td>
<td>-0.30011</td>
<td>0.204128</td>
</tr>
</tbody>
</table>

Figure 3. Passengers carried and goods transported by railways in India in a million passengers-km and million ton-km respectively.
The most important conclusions are as follows:

- there is a strong interrelationship (correlation) between the economic growth and transport sector productivity,
- the relationship very considerable depends on the changes in political situations followed by radical changes in the economy,
- the open economy involves the greater influence of the global economy on the transport sector,
- the business cycles are diffused into the transport sectors by the following ways:
  - Kitchin cycle (3 – 5 years’ periodic cycle) – as inventory cycle is appearing in the transport sector as in other sectors by the usual way of doing the business,
  - Juglar cycle (7 – 11 years) [9] - as a fixed investment is related to changes in vehicle fleets and diversification of activities,
  - Kuznets swing (15 – 25 years) [10] – is diffused into the transport sectors, too; however, the large investments are catalysed more by the changes in political and economic conditions of the given countries and are catalysed by the globalisation (in the economy, free motion of people, etc.) and technology developments,
  - Kondratieff wave (45 – 60 years) [11]– has a direct effect on the transport sector, because the most technological changes are deployed very quickly into vehicle and transportation system developments.

However, the difference in the shifting of economic cycles depend on the regions is not connected with high-speed train development

![High-speed rail history](image)

Figure 4. High-speed rail history
Demand accessibility forecast tool

Figure 5. Flow diagram of the applied methodology

The applied forecasting methodology includes four major cycles:

- concept development (adaptation of the general methods to the forecast objectives and available data sources),
- preliminary actions (selection of the drivers, classification of the rail and geographical sectoring),
- medium-term forecast (including two steps: drivers forecast with inputs harmonisation and demand forecasts) and
long term forecast (by use of dummies, economic cycle models and finalizing the results by „S“ curve fittings).

The methodology includes evaluations and harmonisation of results between the major cycles implying that the results must be evaluated together with the stakeholders. Generally, transport inputs are available in limited forms; this methodology has employed analogy investigated by comparing the available historical series of indicators and the evaluation of the “demand size.”

\[ D_{gv} = \sum_{i=1}^{n} c_i \delta_i \]  

where \( c_i \) are the coefficients defining the role of different factors at the regional level rail trips,

\( \delta_i \) is the Kronecker symbol defining the activity of the given factor (it is equal to 1 once the given factor characterises the regional developments and rail trips and zero if not),

\( i \rightarrow \) factors as business, agriculture, industry, trade, science and technology, tourism, rail terminals (this last equals to 1 once the region has medium or large size rail terminal(s)).

The selected and applied indicators for developed countries differ with those of developing countries and are tailored depending on social, economic, technical and technological levels of a country/region. The “s”-curve model [12] approximates the market penetration, and technology adoption, also the speed at which a new technological solution supersedes the previous one.

Dummies identified for this study include the following:

- Integrated High-Speed Train Network connecting all African capitals and commercial centres by 2063
- The continued progress in the development of batteries and improvement of High-speed rail may cut the generalised costs up to 25 % at around 2035
- Nairobi Metro 2030 Strategy modernisation of the existing commuter rail network
- Rail passing through national park significantly promoting tourism.

The methodology was adapted to the forecasting of demand-accessibility of rail transport.
Energy-saving strategies tool

Train tram hybrid applicability

More than 80% of the energy produced in Kenya comes from renewable sources (geothermal and hydro), with increased mobility demand, electric commuter rail service is highly preferred, however, the available power is inadequate to power the whole rail system. By adopting European studies checklist [13] the applicability of train-tram system was explored through city and region characteristics, infrastructure and technical parameters, existing connections and institutional circumstances and morphological matrix was applied to illustrate the features contributing to the train-tram hybrid being the ‘most suitable system solution’ for developing countries.

Table 2. Morphological matrix for applicability of train-tram hybrid for Kenya.

<table>
<thead>
<tr>
<th>Features</th>
<th>Country’s energy source</th>
<th>Traction power system/infrastructure availability</th>
<th>City characteristic</th>
<th>State of urban rail</th>
<th>Tramway corridor</th>
<th>Existing heavy rail vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More than 80% renewable</td>
<td>Inadequate</td>
<td>Low population</td>
<td>Accessible</td>
<td>In operation</td>
<td>Conventional trains</td>
</tr>
<tr>
<td></td>
<td>More than 50% renewable</td>
<td>Electrified infrastructure</td>
<td>Average population</td>
<td>Well capacity utilized</td>
<td>No existing network</td>
<td>Electric trains</td>
</tr>
<tr>
<td></td>
<td>Non-Renewable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diesel-electric trains</td>
</tr>
</tbody>
</table>

Figure 6. Rail demand-accessibility forecast for Kenya
Replacing the diesel commuter trains serving short (urban) routes with electric trams significantly helps reduce energy consumption, and consequently, emission level (in terms of Well to wheels and Tank to wheels) reduces as well, and since Kenya does not have adequate power to run an electrified rail in the whole country yet, the possibility of having train tram with mixed operations on heavy rail tracks would give the country maximum benefits utilising available resources.

**Hipot tool reducing on $i^2R$ losses**

An improved $\eta$ - overall efficiency of train components result in a reduction in energy consumed see equation 23.

$$E_{spc} = \left\{ 0.0172 \times \frac{V_m^2}{n \cdot D} \times \frac{M_e}{M} + 0.2778 \times \frac{R}{n} \times \frac{D'}{D} \right\}, \text{ Wh/t-km}$$

Most electrical machines failure is ascribed to insulation breakdown [14], [15]. Generally, insulation of electrical machines becomes weak over time (a result of ageing, contamination of winding, internal partial discharges, loosening of bars in the slots or in the overhangs, overvoltage etc.), leading to increased $i^2R$ losses

This thesis has proposed an automated Hipot device that performs voltage withstand test, whereby the machine under test insulation, is stressed far beyond what it would typically encounter during nominal use, usually according to standard, the test voltage should be twice nominal voltage plus 1000v. The pass criteria- if there is no dielectric breakdown.

![Figure 7. Block diagram proposed for Hipot (High potential test) device](image)
\[ y = \frac{k}{1+k\beta} x = k_{fbk} x \]  \hspace{1cm} (3)

Whereby when,

\[ k \to \infty, \quad \lim_{k \to \infty} \frac{1}{k + \beta} X = \frac{1}{\beta} X \]  \hspace{1cm} (4)

The output signal is determined only by the parameters of the feedback loop thus, the transmission factor of the system as a whole ("transmission factor of the system with feedback") \( k_{fbk} = \frac{1}{\beta} \), and the error of the output signal in the steady-state tends zero \( \Delta \to 0 \).

Figure 8. An automatic feedback control system of the circuit

Figure 9. Circuit simulation investigating the effects of a load change
Figure 10. Oscilloscope diagram showing the effect of a load change

Switching off the load leads to a significant increase in voltage due to energy stored in the inductor, which is expended via the capacitor. If the insulation of the coils of the device under test is weak, a surge occurs and a test fail is registered. The routine check of an apparatus helps obtain statistical information about its health and defects are detected early. This way, the efficiency of the electrical apparatuses is increased; thus, overall enhancing the performance of rail by reducing $i^2R$ loss emitted to the chassis in form of heat.

**Total impact analysis**

Sustainability is a primary objective of developing future railway vehicles and transportation systems. This thesis recommends the use of simplified and unique index evaluating the total impact is given in the form of total costs induced by all life cycle effects of transportation system related to a unit of transport work (pass-km, or tonne-km)

$$\frac{TPI}{TLCW} = \frac{TOPI}{TLCW} + \frac{TIPI}{TLCW} = TOPI + TIPI,$$

where $TPI$ is the total performance index, $TIPI$ total impact performance index, $TOPI$ is the total operation performance index, $TLCC/TOLCC/TILCC$ are the total/total operational/total impact $LCC$ (life cycle cost) and the $TLCW$ is the total life cycle work. The $TOPI$ defines the operational cost of the given vehicle, & transportation mode is well known and applied by owners, operators, service providers. They use it in selecting the train, evaluation of the mixed fleets determining the optimised transportation chain. While, principally, the $TIPI$ deals with the externality. It is the index that might be used in impact assessment [16] [17]
$$T_{IPI} = \sum_{i=1}^{n} T_{IPI_i} = \frac{\sum_{i=1}^{n} T_{ILCC_i}}{T_{LCW}},$$

Consisting of different groups of impacts. According to the transportation systems: i= safety and security; system peculiarities; environmental impacts; system support; use of resources. An excel table for its application was developed and Excel software was considered due to its simplicity and availability towards an effort to create a user-friendly tool.

The developed excel table contains the following columns:

- Number of rows,
- Region or area of investigation
- Code number – completed from the indexes,
- Group of impact (GI) (depicted by index “i”, in this example i = 1 mean safety and security),
- Sub-group of impact (SGI) (identified by index “j”, where j = 1 is safety),
- Transport means (TM) (indexed by “k”, k = 1, 2, …; namely road, railway, water, and air transport that might be divided into more subgroups, because the rail transport consists of urban or inter-urban rail, passenger and cargo rail etc, the road transport contains the city or urban transport highway transport, rural transport, or cars, buses, light and have vehicles, the water transport can be classified as inland water navigation and marine transport, passengers and cargo ship transport, etc.),
- A number of studied elements or merit, i.e. value of the chosen governing parameter (here for example number of cars in the given regions-it is well understood, the number of elements as usually can be derived from the available statistics references.
- Applied general parameter (in this first application, the safety can be characterised by a number of the accident of the investigated cars in defined regions, that can be calculated as the multiplication of the number of cars by general parameter as an average running distance by general impact factor as the average risk of accident)

ii. applied parameters, their appellations and values (for each parameter that defines – here – the general average running distance per year),

iii. formula (using for determining the general parameter by use of defined, applied parameters) and calculated values,
- General impact indicator
  i. applied indicators, their appellations and values (that defines the general impact),
  ii. formula (using for determining the general impact indicator) and its calculated value,

Outcomes (determined by use of same methods as it applied to the general parameter and general impact indicator calculations),

Cost coefficient (determined by use of same methods as it applied to the general parameter and general impact indicator calculations),

Work (two columns: dimension and value),
Results (summarized in 5 columns: \( \text{TIPI}_{i,j,k,q} \), \( \text{TIPI}_{i,j,k} \), \( \text{TIPI}_{i,j} \), \( \text{TIPI}_i \), and \( \text{TIPI} \)).

This study has adapted the developed methodology to calculate the TIPI safety impact of accidents as external costs, calculating at first, the accident risk using 2006-2015 data (of derailments of a train, level crossing accidents, accidents to person by rolling stock in motion, collisions (excluding at level-crossing accidents), fires). Secondly, dependent on the number of persons involved classifying between injuries and fatal accidents. The cost conversion was estimated from the willingness to pay for a country[18], [19].

![Figure 11. TIPI for safety aspect (rail accidents) for selected regions](image)

Although cost conversion is not standardised and rather depends on the country’s economy and Germany has higher willingness to pay to avoid casualties their safety index in terms of index is visibly higher than other EU selected countries.

The second adaptation was for calculating the TIPI environmental aspect of GHG emission factor depending on energy consumption following EN 16258 standards. During the adaption of the methodology in the study, there were identified difficulties in sourcing data that are directly-measured from the Kenya rail service, and thus, standard/default values were applied. Which is not uncommon with transport-related data as they are sometimes unavailable or limited depending on with, the economy and society development, the related technology progress & the accessibility and affordability.

This methodology adapts to accept inputs from regions of the same characteristics in terms of economic, social, geographical and technical factors as the investigated region and results to reliable/acceptable results. It is also possible to add specific indicators/parameters column in the excel table. As compared to a study by Chester and Horvath [20] our developed
methodology agrees with their studies that showed a large difference between rail transport operated in different regions based on energy consumption during vehicle’s active operation. The developed methodology user-friendly can be applied for evaluating the total impacts of transport vehicles, transport companies, regional transport systems, and transport means.

New scientific results

Thesis I

By analysis of the interrelationship between the characteristics of railway transport and economic cycles, I have found that economic cycle is connected to the railway transport development (starting with the steam machine but later time gaps were appearing between developing and developed countries).

- I found that the business cycles are diffused into the transport sectors by the following ways:
  - Kitchin cycle (3 – 5 years’ periodic cycle) – as inventory cycle is appearing in the transport sector as in other sectors by the usual way of doing the business,
  - Juglar cycle (7 – 11 years) - as a fixed investment is related to changes in vehicle fleets and diversification of activities,
  - Kuznets swing (15 – 25 years) – is diffused into the transport sectors, too; however, the large investments are catalysed more by the changes in political and economic conditions of the given countries and are catalysed by the globalisation (in the economy, free motion of people, etc.) and technology developments,
  - Kondratieff wave (45 – 60 years) – has a direct effect on the transport sector, because the most technological changes are deployed very quickly into vehicle and transportation system developments.

- I found that mapping the changes of the economic developments measured by the GDP, as shown in Figure 1 (a gap between the well and less developed European countries), allows using the historical data of well-developed countries and dating back’ economic developments for selected Sub-Sahara countries shows they are about 50 years lagging see Figure 2. In addition, I found that in developed countries the Kondratieff cycles time span is reducing not as in developing countries

- I found that that the developed countries cycles related to rail infrastructure but not identifiable with developing countries

- I found that different in shifting of economic cycles depend on the regions is not connected with high-speed train development

Related publications [4], [5], [13]

Thesis II

I have developed a methodology for forecasting the demand in railway travel following the verified methodology developed as a project supporting the Clean Sky Joint Undertaking (as the largest program supported by European Union’s Horizon 2020 that I participated), uses the data sourced from large data banks
• After sensitive preliminary analysis, I have defined the major indicators contributing to the future development of rail transport identified in this thesis, (i) societal and cultural indicators represented by the total population, education level and GINI index (ii) economic indicator represented by changes in GDP (iii) technological indicators represented by the volume of passenger-km and tons of goods-km transported and electric power consumed, Kwh per capita
• I have identified the sensitive indicator that responds to the developing countries different from developed countries. (Like using enrolment of secondary education to show productivity instead of the percentage education government expenditure as applied for developed to estimate the research and development. While the GINI index is used for developed countries to estimate travelling money budget analysing the competition between air and rail, the developing countries adopt electric power consumed per capita indicator to evaluate readiness in technological advancements in the sector)
• I built the methodology based on 4 steps: concept development, preliminary actions, medium-term forecast, long term forecast see Figure 5 verified in Figures 6, harmonised and have clear steps for policy-makers
• I found that the demand for a functioning rail system is increasing rapidly, and the economy of Kenya is well growing, the technological solution in use is long overdue for overhaul see Figure 6.

**Thesis III**

I have developed methodology for total life cycle evaluation (including cost, emission or safety ) with using simplified unique total performance index (TPI) estimating the total impact which is given in the form of total costs induced by all life cycle effects of transportation system related to unit of transport work, passenger-km (pkm), or tonne-km (tkm) see equation 5, that uses available data from data banks (statistical bureaus), especially data-mine data (like railway track construction, and adapted simulated data from given regions) (like endured and cost associated with fatalities)

• I have defined the total performance index as a sum of total operational performance (TOPI) and total impact performance index (TIPI) including short and long term direct, indirect and externality
• The total impact summarises the impact of safety and security; environmental impacts; system peculiarities; system support; use of resources see equation 5 that can be calculated separately as impacts and all the effects see equation 6
• By adapting this methodology, I found that a shift from diesel to electric commuters would not only have the tank to wheel GHG emission factor at zero but would also lower well to wheels GHG emission factors by 81.8%
• I adapted the methodology to evaluate for the safety index of selected European countries and found that the cost conversion is not standardised and rather depends on the country’s economy thus presenting difficulties in comparing countries. However, though Germany has a higher willingness to pay to avoid casualties their safety index in terms of rail accidents is significantly higher than other EU selected countries see Figure 12

Related publications [10], [11], [12], [1], [2], [3],[6], [8], [9], [10].
Thesis IV

I accounted the technological advancements, effortless adaptability of future systems and constrained electrical aspect in developing countries (Kenya), and I found that strategies such as the train-tram hybrid are very actuality for countries rebuilding rail systems. I have proposed an automated Hipot device that helps detect degrading insulation thus saves on $i^2R$ losses emitted to the chassis in form of heat.

- I used the morphological matrix to illustrate the features contributing to the train-tram hybrid being the ‘most suitable system solution’ for developing countries see Table 6 giving the country maximum benefits utilizing available resources
- I have proposed an automated Hipot device that performs ‘voltage withstand test’, which detects insulation failure that is associated with $i^2R$ losses Figure 7 and verified that its output signal error at steady-state error tends zero see equation…
- I have demonstrated on how to acquire 3kV (high voltage testing) from a normal 220V/50Hz source and verified that the circuit responds to an insulation breakdown

Related publications [7]

Thesis V

I have developed a series of tools, for supporting the policy-makers (of developing countries with a stagnated rail system for a long period) making more explicit effects of technological development on future strategic management

- I have developed a total performance index for evaluation of transport strategic developments demonstrating by application to the railway system
- I have developed an understandable and easily useable forecasting methodology for prediction demand in the transportation system
- I have found and demonstrated specific effects of economic cycles on developing countries
- I have proposed methods for increasing the energy efficiency of the railway system in Kenya

Related publications [3], [4], [7], [10]

Own related publications

Journals


Scientific conference


References


Infrastructure in Low-Income Countries in Sub-Saharan Africa and South Asia,” *Sustainability*, vol. 11, no. 16, p. 4319, 2019.


