SUSTAINABILITY-FOCUSED MODELS TO SUPPORT THE STRATEGIC RAIL DEVELOPMENT PROCESSES IN EMERGING COUNTRIES

PhD Thesis Booklet

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Budapest, 2020
Summary

Transport has a determining role in the economy and it is in focus of strategic development planning and actions. It acutely holds true for developing country. Countries of Sub Sahara Africa region, especially Kenya having disrepair, bad condition railway system requires special support in redeveloping their railways. The future developments are based on economy, societal and technology changes and depend on vision and actions of the policymakers, strategic plans and actions and their harmonisation by legislation and financing supports. It is a controllable stochastic process.

There are many different projects and dissertations deal with management and development of the railway systems including infrastructure, railway vehicles and the systems generally. This dissertation has an overall objective adapting and developing tools supporting the strategic development of the railway system in developing countries. It does not deal with political-legal or financial support that depends very on policymakers, common visions of stakeholders and financial conditions of the given countries. This dissertation has clear scientific approach and it uses a methodology based on (i) systematic approach, (ii) developing the supporting tools and (iii) combining, interconnecting the micro and macro-level studies.

The thesis adapts, improves and develops supporting tools as systematic description and modelling the developments, demand estimation/forecasting, the interaction of developments with economic cycles, using the new technologies, solution for improving the railway system performance, created a novel total impact analysis method and demonstrates the applicability of this model on Kenya railway.

The research has resulted in the following theses:

- I have applied a systematic approach to railway system strategic management, introduced a general system description and controllable stochastic model, identified required models, tools, developed some specific tools and demonstrated the applicability of such tools’ systems.
- I have developed and adopted the forecasting methodology to Kenya Railway systems with an estimation of the demand in future passenger’s travel and freight transportation.
- By analysis of the interrelationship between the characteristics of railway transport and economic development, economic cycles, I have identified a gap between the developing and developed countries and characterised the major effects of economic cycles on the railway system developments in developing countries, especially in Kenya.
- I have adapted the technology identification, evaluation and selection methodology to Kenya railway and have demonstrated its applicability to micro
and macro levels, namely by developed Hipot testing methodology and introduction of the hybrid tram-train systems.

- I have developed methodology for total life cycle evaluation including cost, emission, 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 as direct, indirect and external impact related to unit of transport work, passenger-km (pkm), or tonne-km (tkm).

The dissertation describes the adapted and developed methodology, tools, their investigation, verification and concept validations and implementation into the strategic management planning. It may support the strategic development and actions of the developing countries by scientific, objective tools and methodology developed.

The forecasting methods and technology identification, evaluation and selection methodology, as well as the total impact estimation, had been successfully applied to the small aircraft demand estimation (part of Clean Sky 2 European mega project) and developing and impact estimation of the future small electric and hybrid-electric aircraft and e-mobility impact estimation (in Hungarian national EFOP-3.6.1-16-2016-00014 project: IDEA-E - Investigation and development of the disruptive technologies for e-mobility and their integration into the engineering education).
<table>
<thead>
<tr>
<th>External</th>
<th>Internal</th>
<th>Strategy formulation</th>
<th>Strategy Implementation</th>
<th>Evaluation and Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural</strong>&lt;br&gt;Opens neighbouring landlocked countries to port&lt;br&gt;High freight demand (tea, coffee, flowers, titanium ore, copper,&lt;br&gt;Societal&lt;br&gt;High passenger demand&lt;br&gt;Unavailable ‘last mile’ connection&lt;br&gt;Public awareness of sustainable solutions&lt;br&gt;Task&lt;br&gt;Limited past data&lt;br&gt;Uniformed public on the advantages of sustainable transport&lt;br&gt;Adoption of energy-saving strategies</td>
<td><strong>Structure</strong>&lt;br&gt;Limited size/capacity&lt;br&gt;Old, Non-electrified, monorail&lt;br&gt;Makes corridor through the country&lt;br&gt;<strong>Culture</strong>&lt;br&gt;Not attractive to the motorist, thus leaving the large parking spaces (park &amp; ride) empty&lt;br&gt;Passengers travelling with colossal luggage, esp. during holidays&lt;br&gt;Fare based on distance&lt;br&gt;<strong>Resources</strong>&lt;br&gt;Insufficient maintenance of skilled workforce&lt;br&gt;Inadequate professionals due to limited degree programs (Transportation Engineering)</td>
<td><strong>mission</strong>&lt;br&gt;To increase capacity, efficiency, reduce emissions and adapt to creativity &amp; innovations</td>
<td><strong>Strategies</strong>&lt;br&gt;Identify available &amp; applicable greener technological solutions&lt;br&gt;Evaluate available capacity and forecast growth and survival&lt;br&gt;Analysis of direct, indirect and externalities</td>
<td><strong>policies</strong>&lt;br&gt;Enabling transformative technology&lt;br&gt;Formulate emission reduction targets&lt;br&gt;Reinforce efforts towards combating externalities&lt;br&gt;Fare policies&lt;br&gt;Provision of incentives, e.g. for low carbon emission&lt;br&gt;Separation of passenger and freight operations</td>
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Table 1. Strategic management model for developing a strategic plan in railway transport Kenya
Strategic rail management planning as a controllable stochastic development process

Figure 1. A simple controllable stochastic model of the coming future

At first look, the transport is unsustainable, because it is resource-intensive and environmentally harmful. However, according to the definition of sustainability and performances of the operations today, the modern trains are sustainable, due to providing mobility, effects on the economy, efficiency and safety, etc.

Investigation of the processes that bring the future, may result in a simple, controllable stochastic model (Figure 1). As seen, the progress in sciences and technologies composes the objective stochastic part in the development of the future and determined the predicted (or predictable) future. On the other hand, the economy and society have a vision on the future that they (stakeholders) would like to have. This is the subjective part of the process, resulting in the expected or desired future. The estimated difference between the predicted and expected futures can be used for controlling the future. This control includes the definition of vision, strategic goals, allocation of resources (financial support) for maintaining the activity (including the regulation, supporting the large research and innovation projects, etc.).

As a result (after applying the control activities) the future will appear in its real form that is different from the predicted and expected one. After estimation of this new real future, the process of control can be developed for the next time period. Let us suppose the state of the sector of the economy, as a railway system might be represented by its state characteristics, $x$. The future developments characterizing by the state vector is appearing in the form of a stochastic process with continuous time and space. This future depends on the applied actions that can be defined as control.
The space of possible changes in the state vector, \( x \), can be divided into the well-defined discrete subspaces. Therefore, the stochastic process of development might be approximated by a well-known stochastic process, like Markov process of continuously time and discrete states (Figure 2).

![Figure 2. Controlled stochastic process of future developments](image)

In practice (Figure 2), the body or committee having responsibility for strategic planning and actions may identify the development state as situation \( S_i \). As shown, depending on the intended or planned future developments, the body may make a decision (choosing the required resources, \( R_{req} \) from the possible, disposable resources, \( R_{disp} \)). It means, the resources or set of possible actions, including legislation, financing, introducing new technologies, supporting some target part of society as providing free tickets for pupil and students, etc. After applying the actions as control, the economic sector will move into the next situation, \( S_j \), randomly. The situation \( S_i \) is one of the set of possible situations determining by the applied control and environment, like the global economy, changes in social habits, etc. Even the estimation of the situation may have errors. Now, the actions required for reaching the next step in future developments must be determined and applied. By this way, the future development looks like a controlled stochastic process.

The situation chain process can be given by the following mathematical representation:

\[
c(t) : \quad (x_0, t_0, \omega(t_f \in [t_0, t_0 + \tau]; R_{disp}(t_0), R_{req}(t_0), \ldots), \quad (1)
\]

or in a more general approach:

\[
c(t) : \quad (P : \sigma_0(t_0) \rightarrow \sigma_f(t_f \in [t_0, t_0 + \tau]) \in S_f \subset S_a, R_{disp}(t_0), R_{req}(t_0), \ldots), \quad (2)
\]

Where \( x_0 \) is the vector of parameters at the initial (actually starting) state at \( t_0 \) time; \( \sigma \) is the state of the system in the given time; \( \tau \) is the available time that is enough for the transition of state vector into the set of \( \omega \) not later than, \([t_0, t_0 + \tau]\); \( P \) is the problems how to transit the system from the initial state into one of the possible states \( S_f \subset S_a \) not later than \( \tau \). In this approach, the decisions and actions will appear in the elements of the transition matrix transiting the situation.
process from one situation into the other. This approximation model depicts a scientific approach to working on the strategic management and actions and selecting the optimal solutions, actions, while this very depends on the political decisions that often out of dry scientific decision support. The political decisions might be studied by using the method of subjective analysis or optimisation in case of a lack of information and large robustness in constraints. Therefore, it is out of the scope of this dissertation developing and applying strong scientific methods.

Figure 3. Description („Tetris”) of the strategic plan developments

Showing the interaction between the required scientifically established methodology for supporting the policy-makers and leading stakeholders’ group in developing the visions, making a strategic plan, developing the business models, adapting the legislation and financing and defining required actions for reaching the predefined plans.

**Demand-accessibility forecast tool**

The forecast, foresight, business models, business plan, support developing the strategy for achieving the goals of visions. Principally the vision - after definition, the required actions resulting in the predefined vision - can be converted into the roadmap [1].

Foresight[2], [3] - is knowledge (or sound judgment) into a future event that may or may not occur. (This is an act of looking forward.) It provides general inputs for technology policy. Because most developing countries (especially in Sub-Saharan Africa regions) spend limited amounts on research and development, they may use the results of available technology foresight [4], [5].

Forecast - is a prediction of the future based on estimation. It uses methods from simple trend analysis to the complex models dealing with an extensive series of drivers, i.e., indicators having determining influence on the forecasting products or services.

While there a lot of forecast methods available, the real problems, like demand forecast in the given form of travel, need more preliminary study and adaption of methodology [6], [7]. The reason for this is a lack of required prehistorical data-series, missing (or even false) data in statistics; real
drivers might be different depending on the real economic condition, society structure and culture, supporting laws, etc. The time horizon, for which the forecast is planned has a significant effect on accuracy, too. Especially the long-range predictions may have unexpected, understandable errors. Therefore, the philosophy of a methodology developed for forecasting the demand for rail transport is recommended (Figure 4.)

The forecast methodology described in Figure 4. has four major sections:

- 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.”

\[ D_{gv} = \sum_{i=1}^{n} c_i \delta_i \] (3)

\[ o \text{ where } c_i \text{ are the coefficients defining the role of different factors at the regional level rail trips,} \]
\[ o \delta_i \text{ is the Kronecker symbol defining the activity of the given factor (it is equal to 1 once the given factor characterises the regional developments and rail trips and zero if not),} \]
\[ o i \rightarrow \text{factors as business, agriculture, industry, trade, science and technology, tourism, rail terminals (this last equals to 1 once the region has medium or large size rail terminal(s)).} \]

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 [6] approximates the market penetration, and technology adoption, also the speed at which a new technological solution supersedes the previous one. The technical developments, the changes/development in the infrastructure and regulatory environment can be accounted as dummy variables. Originally, the term dummy was applied for prediction errors [8] or seasonal and social (e.g. holiday, festival) effects. Dummy variables were applied to define the variables equal to yes or no, quantitatively 1 or zero. These variables are proposed in the applied methodology to take account of all the effects of generating step changes. For a more
mature approach, strong and soft dummies might be defined. Strong dummies cause step changes in the future, while soft dummies introduce step changes in the rate of changes.

Figure 4. A flow diagram of the applied methodology
Dummies identified for this study include the following:

- Standard railway gauge phase one implementation in the year 2018
- Nairobi to Malaba with connectivity to Kisumu, Uganda and Rwanda (phase 2) Opening to landlocked countries, 2021
- Expanding Nairobi Commuter Railway Services system that involves the upgrading of the Commuter Core System (existing commuter rail line); construction of a railway line from JKIA to the Syokimau Railway Station, 2024

The methodology was adapted to the forecasting of demand-accessibility of rail transport Kenya and results are presented below.

![Figure 5. Rail passenger demand-accessibility forecast for Kenya](image1)

![Figure 6. Rail freight demand-accessibility forecast for Kenya](image2)
The interrelationship between rail transport and economic cycles

On the other hand, nowadays, good strategic plans try to take into account the effects of economic cycles on future development, on investments and demands. Figure 9. shows the power spectral density (PSD) of the GDP growth rate of the United Kingdom (UK) available for the last 700 years[9] and demonstrates appearing the cycles in economic developments.

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,
o Juglar cycle (7 – 11 years) [10] - as a fixed investment is related to changes in vehicle fleets and diversification of activities,

o Kuznets swing (15 – 25 years) [11] – 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,

o Kondratieff wave (45 – 60 years) [12] – has a direct effect on the transport sector, because the most technological changes are deployed very quickly into vehicle and transportation system development

The analogy in the changes of the economic developments measured by the GDP, as shown in Figure 10 (a gap between the well and less developed countries), allows using the historical data of well-developed countries.

Figure 10. Real economy developments of selected countries (left) and curves “dated back” for Hungary and Poland (right) (used input source: WDI)

The same analogy for developing countries is applied see Figure 11 ‘dating back’ economic developments for selected Sub-Sahara countries showing 50 years lag.
However, the difference in the shifting of economic cycles depend on the regions is not connected with high-speed train development.

**Energy-saving strategies tool**

According to Association of American Railroad’s opinion [13], the future rail will use hundreds of sensors built into the tracks, and vehicles and that will allow to make automated inspections of tracks, advance fuel/energy management, so-called positive train control, that all will improve the efficiency. In such high automation cases, of course, the role of operators shifted from active monitoring and control to the passive monitoring, that even might be controlled from considerable distances. Therefore, new elements, like monitoring the mental condition of operators [14], [15]. The fully autonomous train and railway transport require relevant code defining the responsibility on risk detection and elimination [16].

It seems the future technologies will have improved efficiency, safety and will reduce the environmental impact of future transport systems. Investigation of this technological effects requires developing general approaches on the system levels and specific methods on the sub-system, vehicle level. As an example, it was investigated the energy-saving strategy by use of train tram hybrid transport for Kenya. The study was performed by adopting the European studies checklist [17] 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 II. The dot 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>
<th>Future adaptability to advancement in technology</th>
<th>Train-Tram hybrid</th>
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<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>
<td>e-mobility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 50% renewable</td>
<td>Electricified infrastructure</td>
<td>Average population</td>
<td>Well capacity utilisation</td>
<td>No existing network</td>
<td>Electric trains</td>
<td>Charging station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Renewable</td>
<td>Third rail</td>
<td>High population</td>
<td>Poor performance</td>
<td>New network due</td>
<td>Diesel-electric trains</td>
<td>Regenerative braking</td>
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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.

For demonstrating the importance of the real engineering and scientific study, the system element might be demonstrated by developing 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. Insulation of electrical machines deteriorates with age, contamination of winding, internal partial discharges, loosening of bars in the slots or the overhangs, overvoltage etc.), leading to increased $i^2R$ losses. The proposed device helps track motors insulation health thereby reducing the $i^2R$ losses and promoting overall rail system efficiency.
Voltage divider generates a low-level signal 0-10v proportional to the value of the output voltage regulator 0-300v. The signal from voltage divider is fed to op-amp and the other input signal from a digital-analogue converter. The output from the op-amp \((V_{vd} - V_{dac})\) \(K_{op-amp}\). Where \(K_{op-amp}\) is the gain of op-amp equal 100.

Pulse wave generator forms \(V_{wave}(t)\), and this voltage is compared with the difference \((V_{vd} - V_{dac})\) \(K_{op-amp}\). At the beginning of each period T Switch S1 is closed and when \(V_{wave}(t)\) reaches the value \(V_{vd} - V_{dac}\), Comparator is triggered, and the switch S1 opens.

In the beginning, when the voltage at the output of the regulator is not large, the signal of the voltage divider is small, the difference \(V_{vd} - V_{dac}\) will be large, and the power key will be open almost the entire period. As the output voltage increases, the difference \((V_{vd} - V_{dac})\) will decrease, which will lead to a decrease in the duration of the open state of the key. When \(V_{dac}\) is greater than \(V_{vd}\) the voltage output of op-amp will be -15V, which is less than the minimum voltage of the pulse wave generator, so the pulses at the output of the comparator will be absent, the switch S1 will be kept closed all the time, and the output voltage will cease to increase.

The effect of load variation is simulated by connecting a low-resistance resistor, whose value is less than 100 times that of a permanently connected resistor simulating losses in the inverter at an idle mode. Such a sharp change in resistance simulates a sharp increase in the current of the inverter that occurs during a breakdown. Figure 13 shows the oscillogram signal after connecting and disconnecting the load \(R_n = 100\ \text{Ohm}\) at the output of the automatic regulator.

**Total impact analysis**

Finally, the total life cycle cost and or total life cycle impact on the environment have taken place in strategic development. For example, today, most researchers are investigating the impacts of products or service on climate changes, or in more directly on greenhouse gas
emission. Therefore, the government is introducing laws to supporting the development, market introduction, and operation of electric vehicles, electric transports.

A simplified and unique index evaluating the total impact has introduced [2], [18]–[20]. Which 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)

\[
TPI = \frac{TLCC}{TLCW} = \frac{TOLCC}{TLCW} = TILCC = TOPI + TIPI,
\]

where TPI is the total performance index, TOPI is the total operation performance index, TIPI total impact 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. [21], [22]

The TOPI defining the operational cost of the given vehicle, given transportation mode, is well known and applied by owners, operators, service providers, used in rail for evaluation of the mixed fleets determining the optimized transportation chain. While, principally, the TIPI deals with the externality. It is the index that might be used in impact assessment.

The TIPI summarises all the impacts:

\[
TIPI = \sum_{i=1}^{n} TIPI_i = \frac{\sum_{i=1}^{n} TILCC_i}{TLCW},
\]

where i = 1, 2, … n defines the different groups of impacts. According to the transportation systems, i = safety and security, system peculiarities, environmental impacts, system support, use of resources.

The TIPI for a group of impacts can be determined as the sum of the different effects:

\[
TIPI_i = \frac{\sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{r} N_{j,k,q} p_{j,k,q} t_{j,k,q} \sum_{v=1}^{u} o_{j,k,q,v} c_{j,k,q,v}}{TLCW_{j,k,q}} \quad \forall i,
\]

where j = 1, 2, … m depicts the subgroups of impacts, while k = 1, 2,… l defines the transport means, q = 1, 2, …, r represents the types or groups of the given transport system, v = 1, 2, …, u identifies the different forms of consequences, N is the number of sub-sub-group elements contributors to the impact, like number of vehicles defined by q, p is the parameter of the given types or group of system elements causes the investigated effects, I is the impact indicator of the given system element, o the outcomes/consequences of impact defined by I or caused by the events, situations associated with the I indicator, c is the conversation coefficient for calculating the (external) cost, and work done W during the investigated period defined by p. It means, if the p is the parameter of function given in the form of an average annual unit, then the W should be related
to the year, too. For instance, if the N defines the number of vehicles and p is the annual average running of the vehicles, then the W equals to p

This dissertation 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 [23], [24].

Figure 15. TIPI for safety aspect (rail accidents) for selected regions

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

Figure 16. TIPI, environment aspect, GHG emission factor in € CO2e per passenger-km for diesel with biofuel proportion type of passenger train
The second adaptation was for calculating the TIPI environmental aspect of GHG emission factor depending on energy consumption following EN 16258 standards. During the adaptation 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. However, Kenya derives 87% of the total electricity from renewable sources (hydro & geothermal), consequently the adoption of electrically powered rail transport would lower the indirect emission factors by 81.8%.

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 [25] 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.

Figure 17. Proportions for electricity production in Kenya.
New scientific results

Thesis I.
I have applied a systematic approach to railway system strategic management, introduced a general system description and controllable stochastic model, identified required models, tools, developed some specific tools and demonstrated the applicability of such tools’ systems.

- The systematic approach to strategic development resulted to a formal model that is based on society, economy and technology developments supported by managing actions, legislation and financing and driven by improving the efficiency and minimum total impact.
- The introduced controlled stochastic model of future development might be approximated by a Markov chain.
- I have identified the set of indicators characterising the Kenya Railway system developments.

Related publications [3], [4]

Thesis II.
I have developed and adopted the forecasting methodology to Kenya Railway systems with an estimation of the demand in future passengers travel and freight transportation.

- The improved methodology contains 4 step approximation: concept development, preliminary works medium ad long term forecasting.
- I have developed a method for handling the missing data based on harmonization with the that available for the regions, or countries with analogical economic, societal and technological developments levels.
- The quality of forecast was improved by using the classical forecasting methods to medium – term and “S”- curve, Gompertz model for long term forecasts.
- I have identified and applied some developing country, Kenya specific drivers and 4 dummies characterising the future developments of the Kenya railway system.

Related publications [10], [11], [12],

Thesis III.
By analysis of the interrelationship between the characteristics of railway transport and economic development, economic cycles, I have identified a gap between the developing and developed countries and characterised the major effects of economic cycles on the railway system developments in developing countries, especially in Kenya
• The identified gap 50 years gap related to the developed countries and about 35 years behind the Central – East European countries may allow to compare and use of historical best practice to developing the strategic plan and actions.

• There was found the inventory Kitchin, fixed investment Junglar cycles and Kuznets swing diffusion into the transportation systems are depending on the political, legal, financial actions of investigated counties, namely Kenya, while, the Kondratiev (Kondratieff) waves influenced by the global economy, globalization.

• I found that in developed countries the Kondratieff cycles time span is reducing not as in developing countries because of the delay in new technology investment.

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

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

**Thesis IV.**

I have adapted the technology identification, evaluation and selection methodology to Kenya Railway and have demonstrated its applicability to micro and macro levels, namely by developed Hipot testing methodology and introduction of the hybrid tram-train in systems.

• I have cancelled from adapted methodology the evaluations based on technology compatibility and technology impact matrices because of the countries of Sub Sahara Africa regions and especially in Kenya the railway system such old and obscurantist that has not allowed the applications of these scientific approaches.

• I have developed and proposed an automated Hipot device that performs ‘voltage withstand test’ to demonstrate, how new technologies, solutions may support the efficiency improvements on the microlevel.

• I have studied by using the morphological matrices and found that the introduction of hybrid, tram-train system into the urban regions is the most suitable for Kenya because of the excellent clean mixed energy generation.

Related publications [7]

**Thesis V.**

I have developed methodology for total life cycle evaluation including cost, emission, 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 as direct, indirect and external impact related to unit of transport work, passenger-km (pkm), or tonne-km (tkm).
- I have improved the methodology introduced by Chester and 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, that can be calculated separately, too.
- 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 depending on the mix of electric energy source, for Kenya having rather clear energy generation system by factors by 81.8%.
- I adapted the methodology to evaluate for the safety index of selected European countries and found that it wasn’t justifiable to compare TIPI for different countries because the cost conversion is not standardised and rather depends on country’s economy. 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 countries.

Related publications [1], [2], [3],[6], [8], [9],

**Own related publications**

**Journals**


**Scientific conference**


References


