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

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Submitted in partial fulfilment of the requirements for the degree of
Doctor of Philosophy
2020
Executive 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).
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List of Abbreviations

ARMA- Autoregressive multi average model
ARX- Autoregressive Exogenous
BRT- Bus rapid transport
DC- Direct current
Dgv- Demand generation value
GDI- Gross domestic income
GDP- Gross Domestic Product
GNP- Gross national product
Hipot- High potential test
IEC- International Electrotechnical Commission
IEEE- Institute of electrical and electronics engineering
K-Waves- Kondratieff waves
NBER- National Bureau of Economic Research
NEMA- National Environment Management Authority
PPHPD- Passenger per hour per direction
PSD- Power spectral density
PWM- Pulse width modulation
SSA- Sub-Saharan Africa
TILCC-Total impact life cycle cost
TIPI- Total impact performance index
TLCC- Total life cycle cost
TLCW- Total life cycle work
TMB- Travelling Money Budget
TOC- Total operational costs
TOLCC-Total operational life cycle cost
TOPI- Total operation performance index
TPI- Total performance index
WDI- World Bank Development Indicators
Statement of Original Authorship

The work contained in this dissertation has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: _________________________

Date: 27/02/2020
Acknowledgements

Firstly, I thank God Almighty for giving me the strength, ability, opportunity, and knowledge, to undertake, persevere and complete this research satisfactorily. Secondly, my special thanks to Stipendium Hungaricum founded by the Hungarian government for providing financial support to enable me to pursue my PhD at Budapest University of Technology and Economics. I wish to express my deepest sincere gratitude to my thesis supervisor Dr Daniel Rohacs also the head of the department of aeronautics, naval architecture and railway vehicles, for his invaluable guidance, suggestions and support that enabled me to successfully carry out my research. In my journey towards this degree, Prof. Dr Jozsef Rohacs has been a teacher, a role model, a friend, an inspiration, and a pillar of support, thank you very much Prof., I shall eternally be grateful to you.

Special thanks to Prof. Dr Katalin Tanzcos for her unlimited encouragement and mentorship. I wish to recognise our department and faculty admins who have ensured smooth communications throughout my PhD studies. I want to register my appreciation to the entire faculty of transportation and vehicle engineering team for providing a conducive environment for my professional and personal growth. I gratefully acknowledge other the funding sources that made my PhD work possible such as EFOP

A special note of appreciation is due to my home university, Dedan Kimathi University of Technology, for their support and giving me a chance to develop professionally. I’m grateful to my colleagues Utku, Sergey, Dung, Bernard and Vincent as they made the journey easier. Lots of appreciation goes to my mother, my first teacher, my strength, Terasia Nyambura and my siblings, my cheerleaders Shelmith and Jedidah for always believing in me. My husband Daniel for his unconditional love, patience, moral support, and continuously adjusting his schedule to fit my needs. Finally, I dedicate this achievement to the best thing that has ever happened to me, my daughter, Claire, who kept asking me every day when I will finish, it’s done! Mommy is coming home!
Introduction

A strategic document adopted by European commission entitled “Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System” [1] defined ten strategic goals. Several of them indeed highlighted the significance of rail transport: Thirty per cent of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and to meet this goal will also require appropriate infrastructure to be developed. By 2050, complete a European high-speed rail network. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050 the majority of medium-distance passenger transport should travel by rail. By 2050, connect all core network airports to the rail network, preferably high-speed; ensure that all core seaports sufficiently connect to the rail freight. To meet these goals, defined models to guide policy actions and measure progress are required.

Besides, technological advancements, has seen the rail transport making a comeback in developed countries, such developments include: (i) very long-life batteries that allow electric trams and trains to operate over substantial distances “off the wire”; (ii) charging devices that boost battery life by recharging at stops en route; (iii) discontinuous electrification that allows electric trains and trams to “coast” under bridges and through short tunnels where it would be impossible or prohibitively expensive to install overhead catenary; (iv) coordinated acceleration and deceleration of autonomous trains; (v) the Maglev and hyperloop trains.

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. The rail having been established to serve colonial interests, left little room for trade between African countries and is, in fact, incapable of easing the traffic in African cities. According to African Union 2063 strategy [2], 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. That said the strategic objectives differ with regions, varying from entrant to new ventures, to growth and maintenance opportunities, to advancements. This dissertation aims to adapt, improve and develop tools that assist in planning and prioritising different development, investment pathways and management for railway transport through evaluation and control focusing not only in present significant issues but paying a good deal of attention to future significant problems as well.
Main objective

To develop tools for support planning and prioritising different development, investment pathways and management for railway transport, thereby, guiding the decision-makers to understand the current usage, predict the impact of policy interventions and measure progress.

Specific objectives:

i. To develop demand – accessibility forecast tool based on (i) selecting the best drivers (economic, social and technical aspects) with available historical data, (ii) defining the special dummies identified from available business models, roadmaps, technology foresight and analysis of the accessibility, affordability, (iii) forecasting the changes in drivers and (iv) forecasting the demand in rail transport.

ii. To define the interrelationship between railway transport and economics. That involves investigations on the interaction between the rail transport sector productivity, condition and economic cycles. There will be studied the Kitchin and Juglar cycles, Kuznets swing and Kondratieff waves. The set of indicators will be defined and applied to global (World) and local (country or regional level) studies.

iii. To analyse and recommend energy-saving strategies applicable to developing countries such as Kenya. It involves (i) developing an automated Hipot device to assist in the track of motors insulation health thereby reducing the $I^2R$ losses and promoting overall rail system efficiency (ii) evaluating the train-tram applicability to support the rail sustainability and emission reduction and at the same time adapt to the constrained electrical production of the country

iv. To develop and calculate total impact analysis in railway systems, this method (i) determines all the impact (safety and security, environmental impact, cost, cost benefits and sustainability that (ii) are analysed and evaluated on the vehicle and/or on the transportation system levels by generating the total impact index

v. To test the models and their applications recommending size, accessibility, demand, impact analysis, and performance of rail transport system

vi. To integrate the developed models into railway transport strategic management

The data used in this thesis are retrieved from international statistical cites [3]–[6] and other published works (all cited). The missing data were interpolated in some cases; in other cases, demand generated value (dgv) was applied. Gathering and analyses of data assisted in helping understand the need, opportunities, direction and initiatives needed to help advance the rail transport system. At the same time revealing the sensitive indicators that respond to developed
countries differently as compared to developing 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 first chapter investigates the need for support, state of the art, performance, of the rail transport system and system management, future transport always depends on the state of the economy society and natural resource and its managed by policymakers. The support system must help them in a situation and needs evaluation, prediction of possible changes (not only in demand but also in economic and society) available and appearing new technology solutions in their decision making. Such support intensely depends on the economic, social mobility and cultural level of countries. Therefore, the very developed countries practices cannot be applied directly to the developing countries like Kenya the covering tools, rules, methods must be evaluated and adapted to the country level and peculiarities.

The second chapter tackles the formulation of models depending on future needs. Reviewing the demand in (i) mobility- the ability to travel by rail, depending on the economic possibility of the potential users and their societal, social habits, (ii) accessibility – availability of the rail infrastructure and characteristics of other transportation means, and (iii) affordability – provision on acceptable costs to users. The applicable models are identified & analysed, followed by the interrelationship between rail transport and economics. Due to technology advancements, and more effortless adaptability of future systems, energy-saving strategies applicability to micro and macro levels (the train -tram hybrid and timely maintenance, Hipot test is proposed to improve the overall efficiency of the rail system) and aspects of total impact analysis are reviewed.

The third chapter deals with data evaluation & harmonisation to user input data to the developed models, putting into consideration all key aspects and indicators. It includes the definition of dummies and demand generated values for regions with limited data. The applicability of the models is tested in a simulated environment in Matlab and the process of analogy from the pattern of past data & experiences. The impact analysis model adapts to a developed excel table, and the results are presented

The final chapter deals with the integration of models; this includes analysis of developed models and developing strategic management support for the developed models.
Chapter 1: Models supporting the strategic rail development processes

Rail transport is such an essential component of contemporary society, a key element in achieving significant environmental and transportation goals. Appropriate strategies and policies need to be devised to maximise the benefits and minimise the inconveniences. In developed countries, rail transport is a matured industry which is experiencing a comeback after a period of decline, due to advancement of technology. The strategic objectives differ with regions, varying from entrant to new ventures, to growth & maintenance of opportunities, to advancement. There is no developed economy, based on outdated transport structure. How can Africa leapfrog its way into the future?

1.1 STRATEGIC RAILWAY TRANSPORT DEVELOPMENT PROCESSES IN EMERGING COUNTRIES.

![Figure 1. Rail traffic density in Sub Sahara Africa (SSA)](image)

Generally, the rail network was built along with first railway developments in World [8], [9]. However, as Figure 1. shows it had at least three significant problems:

- it serves the harbour network and colonisation interest,
- it uses very different solutions (rail-gauge), and

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1 Sub-Sahara Africa (SSA) in this dissertation is used interchangeably with Africa, defined to exclude six African countries: Mauritius, Algeria, Libya, Egypt, Morocco and South Africa.
Chapter 1: Models supporting the strategic rail development processes

- it has not been well maintained and developed for the last 50 – 80 years.

There is a reason why rail freight traffic in Africa accounts for only 7% of the global total, and for passenger traffic, this share falls to 2% [10], [11]. The state of rail performance is poor despite Africa being a hub of exports. The rail network is characterised by ageing tracks and tracks components, deficient signalling and communications services which compromise operational safety, infrastructure lacks uniformity (e.g. different gauges) & inadequate maintenance. Figures 2 shows that the Kenya railway transport role has a severely lagged as compared to the railway transport of developed countries.

![Figure 2. Comparison of rail density, total track in km and productivity of Kenya and selected developed countries](image)

Nowadays, the role of transport, including railway transport increases because of the rapid development of the global economy and increase mobility. Estimates suggest that if all other drivers of growth were to increase by 10% and transport infrastructure were to stay constant, then realised growth in income would be just 9%, i.e. 1% point less than it otherwise would have been [12]. In addition, about a third of the price of goods is related to transport, logistics and defence [13],[14]. Therefore, their future strategic development is an essential and an actual task required not only economical but a technical, technological and even technical advisory support, too.
Management deals with/control the processes, people or things while strategic management manages future operations. As it has known since the definition of 5 P’s [15] plan, ploy, pattern, position and perspective, the strategic management is a more dynamic and less predictable process than the management. Kenya has an ambitious strategic project defined by Kenya vision 2030 [16]–[18] According to this; the railway is an essential element towards placing the country as a central infrastructure service hub for the East African Community (EAC) region and beyond [19], [20].

Import-export requirements drove the first part of infrastructure development Mombasa to Nairobi; however, the World Bank [21], [22] has evaluated these developments as even after this first part construction having a positive influence on country’s economic developments. For instance, the travelling time reduced from 15 hrs to 5 hrs. The future developments must adapt to the social part of the vision 2030.

There were realised a series of preliminary investigations on using the well-known accepted methods [23]–[29] like SWOT, PEST etc. see table 2 & 3 as an example.

Table 1. Kenya railway transport SWOT analysis

<table>
<thead>
<tr>
<th>Strength</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most of the rail network is connected to the port thus improved connectivity to the international market</td>
<td>Naturally, the greatest strength of rail lies in its eco-friendly trait, however in Kenya there exist 0km of electrified track</td>
</tr>
<tr>
<td>High railway freight capacity in comparison to road transport, therefore, generating economies of scale, leading to reduced operations costs per unit transported</td>
<td>The currently built standard gauge, the single-track line serves both passenger and freight making it challenging to maximise profit and creates bottlenecks</td>
</tr>
<tr>
<td>Geographical position - Existence of many landlocked neighbouring countries will encourage the development of high capacity and efficient transport corridors</td>
<td>Policymakers, concentrating too much on road transport and neglecting the light rail transport implementation, slow progress towards urban mobility progress and regional accessibility</td>
</tr>
<tr>
<td>The reduction of the extremely high external costs (noise, pollution, congestion, accidents, etc.) associated with the constant increase in the use of road transport. Thus, higher sensitivity towards environmental and safety issues will result in railways getting more public attention and social support</td>
<td>Continuance uses old technology (meter gauge tracks and diesel locomotives) while the world is moving at high speed.</td>
</tr>
<tr>
<td>There is a capacity constraint – How to match and balance between demand and available capacity</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of large volume of goods such as bulk minerals and commodities that are natural markets for railways</td>
<td>Low flexibility as compared to road transport since the door to door delivery possibilities are limited, thus facing competition from road transport</td>
</tr>
<tr>
<td>Increased demand-growing urbanisation and industrialisation poses new transportation challenges that railways are well suited to handle</td>
<td>Small and inadequate rail network - not able to adjust to doubling of volumes of passengers</td>
</tr>
<tr>
<td>Integrates well with other modes of transport</td>
<td>Financial problems - rail infrastructure is rigid and requires high investments accompanied by high operating &amp; maintenance cost.</td>
</tr>
<tr>
<td></td>
<td>Political instability</td>
</tr>
</tbody>
</table>
Railway transport in Kenya presents lots of strength and opportunities while, according to African Union 2063 strategy [2], one of the flagship projects is Integrated High-Speed Train Network: Connecting all African capitals and commercial centres’ in order to facilitate passengers’ movement across the continent, freight services, factor services and people, reduce transport costs and relieve congestion of current and future systems. This dissertation primarily draws aspiration and aims to provide tools that may guide policy actions and measure rail projects progress and effectiveness for developing economies.

Table 2. PEST analysis for railway transport Kenya

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political</td>
<td>Political challenges during national election cycles impacting negatively on the implementation of planned government programs and projects. Changes in government policy and priorities at national and county levels which leads to a restructuring of ministries and departments of transportation.</td>
</tr>
<tr>
<td>Economic</td>
<td>Macroeconomic factors such as inflation affect the operations of the sector in that the costs of goods and services may be higher during the plan period. Change in the government priorities may lead to budget cuts on some programs, though the sector could be innovative and generate its revenue, for instance through user charges.</td>
</tr>
<tr>
<td>Social</td>
<td>Inadequate rail network with other modes of transport thus unable to serve ‘last mile’ services for both passengers and freight. And unimproved facilities may not capture road motorists’ interests, thus leaving the park and ride parking empty.</td>
</tr>
<tr>
<td>Technology</td>
<td>Advancement of technology in the sector is recognised as a vital element in accelerating rail transport developing and increasing its efficiency. Automated ticketing, energy recovery systems, speed etc. provide an opportunity for efficient service delivery to both passengers and freight. Though it also presents a new form of cyber threat.</td>
</tr>
</tbody>
</table>

After these preliminary analyses, there was developed a model for developing strategic management in railway transport Kenya see table 3. which demonstrates the possible application of such model: 1st level, environment scanning that consists of 2 estimations, firstly, dealing with internal strength and weakness depending on the structural, culture and resources (references) secondly, dealing with external opportunities and threat depending on the societal, task and natural factors facing the management. 2nd level, Strategy formulation, whereby in line with the sector’s strength and weakness, the mission, achievable objectives, strategies, and policy guidelines are defined. 3rd level, Strategy implementation, representing the process by which set strategies and policies through the development of programs, budgets and procedures are put into action. 4th level, Evaluation and control, involves measurement of results and monitoring the progress so that actual performance can be compared with desired performance and when necessary corrective actions are taken.
### Table 3. Strategic management model for developing a strategic plan in railway transport Kenya

<table>
<thead>
<tr>
<th>Environmental scanning</th>
<th>Strategy formulation</th>
<th>Strategy implementation</th>
<th>Evaluation and control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External</strong></td>
<td><strong>Internal</strong></td>
<td><strong>Mission</strong></td>
<td><strong>Objective</strong></td>
</tr>
<tr>
<td>Natural</td>
<td>Structure</td>
<td>To increase capacity, efficiency, reduce emissions and adapt to creativity &amp; innovations</td>
<td>Identify available &amp; applicable greener technological solutions</td>
</tr>
<tr>
<td>Opens neighbouring landlocked countries to port</td>
<td>Limited size/capacity Old, Non-electrified, monorail Makes corridor through the country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High freight demand (tea coffee, flowers, titanium ore, copper)</td>
<td>Culture</td>
<td>Not attractive to the motorist, thus leaving the large parking spaces (park &amp; ride) empty Passengers travelling with colossal luggage, esp. during holidays Fare based on distance</td>
<td></td>
</tr>
<tr>
<td>Societal</td>
<td>Mission</td>
<td>Resources</td>
<td>Notice of incentives, e.g. for low carbon emission Separation of passenger and freight operations</td>
</tr>
<tr>
<td>High passenger demand</td>
<td>Objective</td>
<td>Notice of incentives, e.g. for low carbon emission Separation of passenger and freight operations</td>
<td></td>
</tr>
<tr>
<td>Unavailable 'last mile' connection</td>
<td>Task</td>
<td>Limited past data Uniformed public on the advantages of sustainable transport Adoption of energy-saving strategies</td>
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<td>Public awareness of sustainable solutions</td>
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<td>Notice of incentives, e.g. for low carbon emission Separation of passenger and freight operations</td>
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<td>Notice of incentives, e.g. for low carbon emission Separation of passenger and freight operations</td>
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1.2 INFORMATION AND INPUTS SUPPORTING STRATEGIC MANAGEMENT

Following table 3, the models need a real indicator to measure progress towards attaining the goal. Upon review of sustainable transport, many authors [30],[32],[33],[34],[35] have defined the following:

Baseline (or benchmark) – A standard or point of reference against which things may be compared.

Goal – desired achievement/performance.

Objective – way to achieve a goal.

Target – a specified, measurable, attainable, realistic, time-bound objective.

Indicator – a selected and defined variable measuring progress towards an objective.

Data indicator – values used for indicators.

Type of Indicator – nature of data used by an indicator (qualitative or quantitative, absolute or relative).

Indicator system – a process for indicators description, data collection and evaluation and results implementation.

Indicator framework – a conceptual structure that links indicators to a theory, purpose or planning process.

Indicator set – a group of indicators chosen to measure overall progress toward goals

Index – a group of indicators, aggregated into a single value

The indicators can be classified depending on their application purposes and the users’ goals:

Classification I.

- **Contextual indicators**, enabling the attainment of broadly agreed strategic objectives to be monitored for their impact on sustainable development objectives, where these involve co-operation with partners engaged in the provision of development assistance; such indicators need are developed in consultation with these partners;

- **Influenceable indicators** applied specifically to monitor and measure the performance of enterprise networks’ programmes in delivering sustainable development objectives which influenceable, including the performance of ‘client’ organisations;

Classification II.

- **Policy indicators**, those summarises the key facts and trends or goals about transport and environmental sustainability, show rates of improvement (or worsening), appropriate for highest level policy-makers.
Predictive indicators use to make policy indicators, provide predictive or explanatory power for policy indicators, and applied among experts or policy advisors;

Background material (indicators), those are raw data, measurements, survey results, the output of models and used by experts to build predictive and policy indicators,

Classification III.

Social indicators, measures the impacts on equity, human health, community liveability, community cohesion, as well as the effects on historic and cultural resources and aesthetics.

Economic indicators, those are applied for evaluating the economic development refers to a community’s progress toward economic objectives such as increased income, wealth, employment, productivity and social welfare, (welfare - as used by economists - refers to total human wellbeing and happiness),

Environmental indicators, provide a test for the achievement of environmental sustainability,

Classification IV.

Descriptive indicators describe the actual situation about the main environmental issues, such as climate change, acidification, toxic contamination and wastes in relation to the geographical levels at which these issues manifest themselves,

Performance indicators, compare (f) actual conditions with a specific set of reference conditions (as the distance between the current and the desired (target) situation (the target situations can be defined by the national or the international policy and they may or must refer to the sustainability),

Efficiency indicators, measure the efficiency of products and processes (here efficiency means desired characteristics, like energy or cost efficiencies, level of emissions and/or waste generated per unit of GDP, etc.),

Total welfare indicators, measure the „total sustainability”, so-called “green GDP”.

Indicators’ measurability may be considered the most important characteristic while other features of indicators are (i) an explicit set of categories linking vision and goals of the future; (ii) a limited number of key issues for analysis; (iii) a limited number of indicators of progress; (iv) standardized measurement; (v) their relationship to the spatial context; and (vi) ongoing assessment integrated into the decision-making.

The railway transport may be characterised by indicators accounting the transport volumes and works done; namely, a number of passengers, passengers km, tons of goods transported and ton-km done. The indicators may be defined as years, months, etc., too. Of course, in case of
investigating the impact of transport on the environment, studying the sustainability, research in efficiency or cost structures, developing the infrastructure and so on, need a wide range of different indicators and indexes [30], [32], [33], [36]. Other information on the inputs follows in 1.4

1.3 FORMAL MODEL OF THE STRATEGIC RAIL PLANNING

![Diagram of strategic plan/actions]

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

It shows 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.

A Controllable stochastic development process

The vision is a synergy of the possible predicted and the desired futures. The possible future can be studied by using the methods of foresight and forecasts [37], [38]. The desired or preferred future is envisioned by the stakeholders that as usually is defined as goals, objectives, and problems to be achieved and/or solved. (See for example [39]. The created business models, business plans may support the achievement of the expected future, having profit on development the new technologies, products and/or services.

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 [40]. Nowadays, the overall goal of all the stakeholders’ visions is to develop a sustainable future. It might be the most used definition of sustainability [41] “… meeting the needs of the present without
compromising the ability of future generations to meet their own needs…”. This approach makes the balance in the economy, environment and society. Because the future depends on the available natural resources, built systems (like large energy generation stations) and new technologies, and available, emerging new technologies, the sustainability has more complex characters[42] (Figure 4).

![Figure 4. A general approach to define sustainability](image)

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 5). As can be 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 including the definition of vision, strategic goals, allocation the sources (financial support) for maintaining the activity (including the regulation, supporting the large research and innovation projects, etc.).
In results (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 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 6).

![Figure 6. Controlled stochastic process of future developments](image-url)

In practice (Figure 6), 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, \( R_{a}^{req} \) from the possible, disposable resources, \( R_{a}^{disp} \)). 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:
\[ c(t) : (x_0, t_0, \omega(t_f \in [t_0, t_0 + \tau]) ; R^{\text{disp}}(t_0), R^{\text{req}}(t_0), ...) \] (1)

or in a more general approach:

\[ c(t) : (P: \sigma_0(t_0) \rightarrow \sigma_j(t_f \in [t_0, t_0 + \tau]) \in S_f \subset S_a, R^{\text{disp}}(t_0), R^{\text{req}}(t_0), ...) \] (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.

1.4 REQUIRED MODELS

**Environmental scanning**

It deals with scanning of the situation and exploring the key factors determining the running processes. While rapid urbanisation is a significant feature of developing countries, [43]–[45], it has created heavy demands for investments in infrastructure giving rise to numerous policy challenges both to make cities work better and ensure overall transport efficiency.

According to Homer Hoyt’s sector theory of Urban Development [46], and Ernest Burgess’ concentric zone theory [47], the cities grow outward from a core district (the Central Business District) towards the periphery with distinct land use zones. However, majority of developing countries cities suffers poor planning and management resulting in urban sprawl, and inadequate transport infrastructure. Rapid urban growth in SSA [48] has presented a demand for rail infrastructure, an opportunity for the state to meet their citizens’ mobility needs.

While, rail infrastructure development brings along economic progression but at the same time it’s associated with externalities, for instance, congestion, noise, pollution, safety etc. The Kenyan rail so far has not been able to exploit the environment-friendly strength trait of the railway since none of the track is electrified. Although the electrical production of the country
is constrained, viable solutions of train-tram hybrid could be explored and ways to promote overall rail system efficiency. The monorail has resulted in bottlenecks, and sometimes a standstill traffics in case of failure of a vehicle en route. Rail infrastructure installation and maintenance is an expensive affair have seen the investment and maintenance management reduce funding, thus stalling and postponement of projects while the freight and passengers’ operations are not separated.

The exploration of external and internal factors, assist in the formation of strategies aimed at providing accessible and sustainable transport system, promoting social-economic growth by creating conditions for deepening economic integration and increasing labour mobility and productivity, meeting the citizens’ needs in terms of cultural habits in transportation.

Foresight and Forecasting models

The foresight model is usually more applied to technological developments and changes in social systems/structure. Technological foresight provides idea and adds more information to a process of long-range thinking and planning. It may be based on using the vision scenario, Delphi model [49], expert questionary etc. For instance, the Hungarian technology foresight programme (HTFP) on transport based on the Delphi survey, generated the possible general trends of Hungarian developments [50]. Analysis of Japanese and the German foresight project [51] showed the possible differences and cultural influences on technology assessment. This thesis explores critical technologies in rail transport already in use in developed countries which would have the most significant impact on the economy and social welfare for developing countries. As it would ensure continued existence in future, i.e. the survival and growth of the sector. Usually, in a sophisticated, modern, dynamic, competitive environments characterised by changes in economic, social, cultural and technological, the rail transport sector often struggles to cope up. The forecast model goes beyond experience and mainly based on theoretical forecasts preventing serious strategy failures/errors. It is developed with flexibility to account future challenges such as continued urban and regional population, step change type of event, changes economic development of a country/region, productivity, education level etc.

Economy and society

Aims to compare the interaction between transport sector productivity and economic development. The societal factors are represented by the population, population density (number of people living on a unit area of land), population of active ages (% of the population aged between 25-56), education level (No of pupils enrolled in secondary education, % of the
population with high-level education), unemployment rates, urbanisation (as % of the population living in urban areas), household (net) income, or Gini index. These social and cultural indicators define a pattern of usability of the rail transport system of potential users that very much depends on the economic development of a region. GDP indicator investigates possible cycles in the rail transport system in efforts to show the interaction between the economic cycles such as (Kitchin and Juglar cycles, Kuznets swing and Kondratieff waves) and rail transport. Further, economic cycles are considered in the forecast tool, and possible step changes in the future demand initiated by the technology and infrastructure development as well as the modification of the related regulations are identified and applied as dummies.

**Impact analysis**

The projected rise of impacts in modes of transportation has necessitated a new rethinking of the evaluation of total impact. While most researchers deal with defined parts (like environmental impact) of the total impact. The total impact calculation methodology includes (i) analysis of all the impacts (environmental impact, safety and security, costs, cost benefits and sustainability), (ii) evaluation on the transportation system level, and (iii) as their total value (including all the related subsystems and elements, i.e. transport infrastructure, transport flow control) and (iv) generation of total impact index. Such an index might be referred to as transport total sustainability index. This study defines the total impact performance index evaluating the total impact in the form of generalized (summarized) costs, specifies its calculation methodology and develops a simplified excel based calculation methods.

On scanning, investigating and identifying the required models follows the development of these specific tools.
Chapter 2: Sustainability-focused models’ development

2.1 DEMAND-ACCESSIBILITY-FORECAST

The term forecast tends to be used to refer to a judgement likely to happen in future, especially in connection with a situation, or asset-quantitative definition of the future demand for rail transport.

*Identification and evaluation of the possible drivers*

Generally, the primary drivers contributing to future development of rail transport identified in this dissertation include: (i) the economy and society development, (ii) the technology progress, (iii) the demand in mobility, (iv) the accessibility and (v) the affordability.

- Demand in mobility refers to the willingness and ability to travel by rail depending on the economic possibility of potential users and their societal, social habits. That means they can pay for the travel, without any fear of travelling, and motivated to save their time. The economic and societal drivers might define these.

- The accessibility as capability of using the provided rail transportation system depends on the infrastructure (network) and characteristics of other transportation means (like non-motorised transport, road and air transportation usability and travel performances as door-to-door time/last mile connection). Therefore, it reflects how the users can reach the rail transport connecting with other modes of transportation, and how time-effective the proposed solution is. Accessibility can be characterised by the performance of the available transportation system, as road network, bicycle/motorcycle network, net of airports, availability of the modal chain centres.

- Affordability means that rail transportation is provided on the level that is accepted (paid) by the user. It is determined by the performance of the rail and costs associated with the entire rail transportation systems’. Therefore, the total operational cost of the rail and the cost of door-to-door travel, including the value of time.

Accessibility and affordability are highly sensitive to the changes in the policy, infrastructure, technology development, & social aspects. Forecast techniques use so-called drivers that are the variables of the forecast models, defining, e.g. the economic and social aspects and their
future evolution. 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 [52] 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.

According to the innovation theory, the future also depends on our actions, our market development. Therefore, the future of rail also relies on the development of a new concept of operations, train performances, applied business models, business plans and the regulatory environment. For example, the continental development Agenda 2063, [2], [53], and Nairobi Metro 2030 Strategy [54] outlining the development of a transport master plan to effectively improve transportation infrastructure and the existing transportation options around the city (modernization of the existing commuter rail network). These actions and events might be defined as dummies. Consequently, several economic, societal and technical indicators and possible dummies were investigated over the selection of the relevant drivers to rail transport demand.

**Applicable models**

With respect to the demand models, this class of forecasts aims to express the passenger demand ($D$) through a series of different factors ($X_1, X_2, \ldots, X_n$), called the independent variables:

$$D = f(X_1, X_2, \ldots, X_n) \quad (3)$$

The review of early publications found that the key factors determining the rail transport demand include the economic growth (principally the GDP), fare (or price) and the demographical characteristics like the population density or the unemployment rate [31], [55]–[58]. Based on the functional relationships between these influencing factors and the passenger demand, the reactivity of the dependent variable with respect to the variation of one factor $X$ could be expressed with the following equation.

$$\eta_n = \frac{\Delta D / D}{\Delta X_n / X_n} \quad (4)$$

This is the demand elasticity ($\eta_n$), which therefore measures the responsiveness of the quantity demanded to a change in the factor $X_n$ while keeping all other variables constant. Knowing the
elasticities (of each \( X_n \)) and defining the future evolution of the independent variables, the projection of the passenger demand could be expressed with one of the following functional forms of the equation [59], [60] (i) linear demand, (ii) log-linear demand, (iii), logit model and (iv) translog demand system.

The linear model

\[
D = \alpha + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \cdots + \beta_n \cdot X_n \tag{5}
\]

where \( \beta_n \) are the respective parameters associated with the independent variables \( X_n \) and \( \alpha \) captures the value of \( D \) when all \( X_n \) is equal to zero. This class of models were extensively used for demand and sales forecasting, since, compared to others - it is relatively easy to estimate and advantageous in interpreting the empirical results [61]. It is valuable that each elasticity of demand depends on the value of the variable, still, the assumption of a linear effect might not reflect the real relationships in the context of the rail transport system development.

The log-linear or double-logarithmic or Cobb-Douglas model [62] specifies the logarithm of the traffic volume as a linear function of the logarithms of the potential independent variables:

\[
ln(D) = \alpha + \beta_1 \cdot ln(X_1) + \beta_2 \cdot ln(X_2) + \cdots + \beta_n \cdot ln(X_n) \tag{6}
\]

This model is the most widely used functional form of the transportation demand models [63], [64] as the \( \beta_n \) coefficients are the respective elasticities (\( \eta_n \)), and the log-linear function is capable of modelling non-linear effects. However, the main drawback of this model is that each elasticity is invariant across all data points, which is powerless in considering novel transportation means (such as a new business jet operation), where the responsiveness of the quantity demanded to a change in one factor \( X \), might be non-linear. This model might also include [64] typical independent variables (e.g. GDP), dummies and special travel and rail transportation specific aspects (e.g. travel distance, average ticket prices, number of trains on the route, service availability).

The logit model considers the market shares of alternative transport modes. It extends the log-linear form to allow a mixture of categorical and common independent variables and to estimate one or more categorical dependent variables:

\[
ln\left(\frac{S_i}{S_m}\right) = \alpha_i + \sum_{k=1}^{K} (\beta_{ik} \cdot \frac{X_{ik}}{X_{mk}}) + \sum_{n=1}^{N} \gamma_{ik} \cdot X_n \tag{7}
\]

where \( S_i/S_m \) is the ratio of the demand \( i \) to the base mode \( m \), \( X_{ik}, X_{mk} \) are respectively the \( k^{th} \) attribute of the mode \( i \), and of the base mode \( m \), \( X_n \) is the \( n^{th} \) common variable to all modes, \( \alpha_i \),
\( \beta_{ik}, \gamma_{ik} \) are the model parameters. This class of model might be used to investigate the sensitivity of the market shares of alternative transportation modes to a change in regulatory or managerial control variables such as the relative prices or the quality attributes. According to [59] the major advantage of the logit model is that the two alternative case yield the logistic curve, which is an S-curve “intuitively attractive and realistically describe” the mode switching behaviour of decision-makers.

The translog demand model is derived from a “flexible” utility or production function that provides a quadratic approximation to the unknown true function. Because of its specifications, all variables \((X_n)\) are interacting with each other and with themselves, which – considering \(X_1\) and \(X_2\) – is characterized by the following functional representation:

\[
\ln(D) = \alpha_1 \ln(X_1) + \alpha_2 \ln(X_2) + \beta_{11} \ln X_1^2 + \beta_{12} \ln X_1 X_2 + \beta_{22} \ln X_2^2
\]

where \(\alpha_1, \alpha_2, \beta_{11}, \beta_{12}, \beta_{22}\) are the parameters of the translog function.

While this method is widely applied to the cost functions of transport industries [59] its primary disadvantages include (i) the complexity in evaluating the coefficients, and (ii) the statistical concerns with over parameterisation due to the presence of numerous interaction terms involving the explanatory cost factors. However, once the required historical time series data are available, simple models like the one proposed by Srisaeng [65]

\[
Y_{GRT} = a_0 + \sum_{i=1}^{n} a_i X_i
\]

might be applied. Here \(Y_{GRT}\) is the indicator of general rail transport (number of passengers, or revenue passenger kilometres) and \(X_i\) specifies the inputs.

However, it is not fully clear, how to manage endogeneity, when the model errors depend on the independent variables. In such a case, the Engel-Granger’s two-step error correction model [66] might be applied. At first the regression equation

\[
y_{it} = \beta_0 + \beta_1 x_{it} + \mu_{it}
\]

must be used to derive the residuals \((\mu_{it})\) and test whether this series of residuals are stationary. Here all the variables are in logarithms, \(\beta\)'s are a set of coefficients, \(x_{it}\) a vector of explanatory variables for \(y_{it}\), and \(\mu_{it}\) residuals. The subscripts \(i\) and \(t\) denote region and time, respectively.

If the residuals show short memory, it expresses that the time series are co-integrated and the second step of estimation can be proceeded to estimate the equilibrium rate \(\theta\) and short-run dynamics \(\lambda_1\) from the following equation defining the changes in \(t\) and explanatory variables.
\[
\Delta y_{it} = \lambda_0 + \lambda_1 \Delta x_{it} - \theta \mu_{it} + v_{it}
\]

(11)

This equation is the short-run (first differences) formation of the long-run model expressed in equation (11). The error correction model is represented by the lagged term of the estimated residuals derived from the regression of the long-run equation. If \( \theta \) is found to be significant and positive, it means that there is a long-run co-integration relationship among the variables specified in equation (11). This approach is also used by Yao and Yang [67] to study the interactions of economic growth and air transport on regional levels of China.

Among the models described above, the log-linear might be the most suitable for rail transport forecasting, due to its advantage in estimating the elasticity values. The new market forecast might be based on survey techniques using the “S”-curve to determine the timing of the replacement of the old technologies. However, once using this method, attention should be paid for the formulation of relevant questionnaires distributed to the relevant experts with adequate past experience in the given domain. According to the literature, it is also recommended to decompose the given problem into more specific and better-described elements being more understandable for the experts of the given areas.

Besides surveys, another potential technique that adequately describes new product or service is based on S-curves and innovation diffusion theory [68], dealing with market penetration. Such an approach might better represent the relationship between technology adoption and time [69], [70] since a new technology covers numerous market penetration and adoption phases with different characteristics. It is reasonable since when a new technology is first introduced, it is often unproven, relatively expensive, and challenging to operate. Standards are not yet established, and practices are to emerge. Therefore, only the innovators - a limited segment of the population - might experiment it at that time.

To describe such S-curves, numerous different mathematical models are offered [63]. The basic extrapolation model - using a logistic curve - first proposed by Tanner [71], such as the followings:

\[
VO = \frac{S}{1 + a \times \exp(-b \times t)}
\]

(12)

This mathematical representation estimates the dependent variable (this time the vehicle ownership per capita: \( VO \)) at the simulation time \( t \), with a saturation level \( S \), and two model coefficients \( a \) and \( b \).

By introducing the casual variables \( (v_1, v_2) \) and several model coefficients \( (c, d, n) \), the equation (12) could be modified to (Tanner, 1978):
Another applicable model is the Gompertz curve that is recommended to be used as a growth curve by Winsor (1932):

\[ VO = S \cdot \exp[-a \cdot \exp(-b \cdot v)] \]  

(14)

Where \( v \) is the primary independent variable, while all the other variables are the same as in the equation (14), the Gompertz curve is probably the most used S-curve model, especially in technology forecast. The technology and product lifecycle follow a typical S-curve. Between the models mentioned and others not cited here, the most often used technique is the Gompertz function [63] due to its flexibility, especially at the beginning and the final part of the curve. However, to clarify the potential application of this class of model for the prediction of transportation systems, the implied elasticity value needs to be analysed. The long-run elasticity is calculated as:

\[ \eta_{LR} = a \cdot b \cdot v \cdot \exp (-b \cdot v) \]  

(15)

Figure 7. shows the character of the long-run elasticity of this coefficient. The \( \eta_{LR} \) is not constant, rather increases rapidly as the independent variable \( v \) raises through the early development stage, before declining gradually to zero as saturation is reached.

Therefore, using the innovation diffusion theory approach and especially the Gompertz function, one could more realistically describe the market penetration and technology adoption. In addition, investigations show [63] that on the long-run technology could also be understood as transportation systems, and therefore the S-curve models could be applied to approximate the development of these, such as the prediction of the total car ownership [72].

![Figure 7](chart.png)

Figure 7. The non-linear characteristic of the long-run elasticity given by the Gompertz curve.

Seeing all the characteristics mentioned above, the approach based on S-curves could bring into play, for example, the following advantages in prediction modelling:
a non-linear approach that - relative to the log-linear models - could realistically represent the attribute of usability/ adoption of advanced rail transport technology in developing countries,

a model structure that does not suffer from the problem of gathering detailed socioeconomic and transportation characteristic data.

offers non-linear elasticity to represent the responsiveness of the quantity demanded to a change of one independent variable,

includes a saturation level where the demand reaches its maximum value regardless of the independent variable(s) (unlike predictions based for example on regressions)

enables to apply a partial adjustment mechanism (to account for lags in the adjustment).

However, real future, real technology development, real future production, they all represent a stochastic process. The Gompertz model (14) might be improved and defined for a stochastic process [72]:

\[ \frac{dVO_t}{dt} = (\alpha_1 - \alpha_2 * \ln(VO_t))VO_t + \alpha_2 * VO_t * d\omega_t \]  \hspace{1cm} (16)

where \( \alpha_i \forall i \) are the coefficients and \( \omega_t \) is the Wiener noise.

This improved model allows to use the approximation by the Markov process and apply a Monte Carlo simulation.

![Figure 8. Worldwide vehicle ownership trends as a function of GDP per capita [73]](image-url)
While the S-curve model is based on the innovation diffusion process to the market, it should be expressed in function of various economic factors. The travelling money budget (TMB) and the total operating cost (TOC) introduces other important indicators. Potential users will choose rail transport when the TMB is reaching the TOC of rail transport (Figure 9). The crossing point of the TMB and the TOC defines the accessibility, which thus represents the starting point of the market penetration S-curve.

![Figure 9. The application of the Travelling Money Budget (TMB) and Total Operating Cost (TOC) to estimate rail transport accessibility (note: curves are only illustrative).](image)

**Further applicable models**

The demand generation value (Dgv), which encompasses the following:

\[ D_{gv} = \sum_{i=1}^{n} c_i \delta_i \]  \hspace{1cm} (17)

- 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 such 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 same principle is recommended in those forecasts for the selected countries with fully or partly available data. The analogical models were recommended to be used only for one or a maximum of two missing input series. The applied hybrid forecast method means that a mixture of forecasted drivers (as available from the databases) and a forecast of the drivers based on analogies was used at the same time. These are expressed based on analogy, depending on the other regional characteristics as the importance of the agriculture and industrialisation, education level, size of population density or attractiveness. Therefore, the available drivers are used to obtain the required, but missing inputs data for the analogical regions with limited data.
The same approach applies to country levels. Our era can be characterised by the revolutionary development of new technologies, wide application of the info-communication technology and economy globalisation. All these significant aspects cause increasing demand in the transportation system that plays a deterministic role in the global economy, supporting the free movement of people and products has an important political role, determines the defence characteristics and depends linearly on GDP[74].

2.2 INTERRELATIONSHIP OF RAILWAY TRANSPORT AND ECONOMICS

Changes in Kenyan GDP and rail transport volumes can be used to study interactions between Kenyan economy changes and the rail transport sector (figure 10); evidencing, changes in GDP causes changes in transport volumes, too. Political instability affects both the GDP and transport volumes, reflected in the early 1990s, during the introduction of the multi-party system Kenya [75].

![Figure 10. Changes (a) and rate of change (b) in Kenyan GDP and rail transport volumes (related to the year 1980 – 2005)](image)

Figure 11. shows the GDP (Gross Domestic Product) of England and the United Kingdom adjusted for inflation and measured in British Pounds in 2013 prices [76]. It’s not easy to use the long-term series of GDP growth for estimating the possible cyclical fluctuation in the economy. Instead of this, the rate of change in GDP (Figure 12.) is used to study the possible cycles in development. Figure 13. demonstrates that there are really some cycles that are appearing in the business activity, as economic growth.
These fluctuations appearing in Figure 13 can be characterised shifts over time between periods of relatively rapid economic growth (an expansion or boom), and periods of relative stagnation or decline (a contraction or recession) [77].

At first, the business cycles were discovered by Juglar [78]. He founded the fixed investment cycle of 7 to 11 years. Later Schumpeter [79] defining the basis of innovation theory, showed that the Juglar cycles are composed of four stages: (i) expansion, (ii) crisis, (iii) recession and (iv) recovery. Next cycles called inventory cycles were found by Kitchin [80]. Principally, the Kitchin cycles are defined by the time lags in information movements affecting the decision making of commercial firms. These cycles long to 3-7 years.

Kondratieff investigated the long-term cycles at the 1920s. He identified 45-60 years long wave cycle [81]. The Kondratieff long waves are called as K-waves or supercycles, too. These waves
consist of alternating intervals between high sectoral growth and intervals of relatively slow growth (Figure 14). A wave is building up from four stages [82]

- **spring** when the debt level is low, consumption is low and well below incomes of corporation and individuals, while the inflation is growing slowly;
- **summer**, the economic environment and growth are pretty good, but the inflation finally gets out of hands, the interest rate may above the 10 %, making debt servicing problematic;
- **fall (autumn)**, that is the “best period”, when the falling inflation and interest rates allow consumers and corporations load up debt without increasing debt servicing obligations, but before its end, the increasing number of borrowers (corporations and individuals) are becoming the Ponzi units (when borrower needs a constant increase of its debt burden for new debt to be used to service the old debt obligations).
- **winter**, that is a depression characterised by popping the autumn bubble while the situation is uncontrollable, deflation decreases all kind of prices, however, “Kondratieff main idea was that the market economy self-heals itself each time it goes into trouble.” [82]

Some other interesting aspects might be underlined. (i) In Kondratieff wave, the inflation increasing during spring and summer and decreasing in fall and winter while this strange disinflation ends with absurd deflation. (ii) The stocks and bonds are moving in the same direction in the first three periods of Kondratieff wave, while during the fourth stage, the stocks and bonds are moving in opposite directions. (iii) The whole Kondratieff wave is one big credit cycle, starting with outstanding credit levels when the authorities are forced to increase the monetary base by printing money, and after 50 – 70 years’ growth it ends with absurd credit levels, and then everything collapses with massive defaults. The fourth business cycle was discovered by Kuznets [84], investigating the cyclical fluctuations of the production and prices. This cycle is called a Kuznets swing: 15-25 years’ infrastructural investment cycle. It seems the Kuznets swing is not an independent cycle, because it appears as a third frequency harmonic of the main frequency oscillation, generated by the Kondratieff long wave cycle [85]. The business
cycles as the periodic processes can be characterised by the amplitude, frequency or period and phase parameters.

Finally, after [79] classification, nowadays, five business cycles are defined: 1.) 3-7 years Kitchin inventory, 2.) 7-11 years Juglar fixed investment, 3.) 15-25 years Kuznets infrastructural investment, 4.) 45-60 years Kondratieff longwave and 5.) 70+ Grand super-cycles [85]. As the cycles have not accurate periods (time intervals), the multiple origins of business cycles were proposed in macroeconomics, as fluctuations in (i) aggregate demand in agreement with the Keynes theory, (ii) credit, (iii) technological innovations, (iv) land price and (v) politics [86]. The real process of the economic developments consists of mixed compositions of the business cycles. The nonlinearities in economics and financing through the missed business cycles cause nonlinear dynamics in economic developments and even result in chaos.

**Indicators and preliminary studies**

So-called a set of indicators can be defined and used for investigating the relationship between the economy and railway transportation systems. The indicator is a variable selected and assigned to measure progress toward an objective [87], [32]. Values used indicators are the *indicator data*. There are several types of indicators, namely qualitative or quantitative, absolute or relative. As usually, the indicators are defined collected, analysing the data and applying the results in the *indicator system*. *Indicator framework* is the conceptual structure linking indicators to a theory, purpose or planning process. *Indicator set* is a group of indicators selected to measure comprehensive progress toward goals. Finally, the *index* is a group of indicators aggregated into a single value.

It might be the most important characteristic of the indicator is its measurability. Other important features of the indicators are (i) an explicit set of categories linking vision and goals of the future; (ii) a limited number of key issues for analysis; (iii) a limited number of indicators of progress; (iv) standardized measurement; (v) they relationship to the spatial context; and (vi) ongoing assessment integrated into the decision-making.

Economic growth is usually measured by the GDP (growth domestic product). It seems like a well simple indicator, but it’s calculation is not so definite [88] and it contains some anomalies, because the GDP may increase by a global company working for export, only, or by moving the headquarter of a large company from one state to another one. Therefore, the economic growth can be identified by GNP (gross of national product) and other indicators as net income, unemployment rate, etc.
The railway transport may be characterised by indicators accounting the transport volumes and works done, namely number of passengers, passengers km, tons of goods transported and tonne-km done or hauled vehicles of passengers movements – seat kilometres offered and hauled vehicles of goods movements – tkm offered to show the utilization/exploitation of capacity, especially by indicator transported tons/network-km. The indicators may be defined as years, months, etc., too. Of course, in case of investigating the impact of transport on environment, studying the sustainability, research in efficiency or cost structures, developing the infrastructure and so on, need wide range of different indicators and indexes [32], [36], [89], [90] for instant, Lahiri and his Colleagues [91] used four coincident indicators (transportation service output index (TSOI), real aggregate payrolls of workers employed in the transportation sector, real personal consumption expenditure (PCE) on transportation services and all employee) for investigating the business cycles in transport. Generally, these indicators reflect information on output, income, sales, and labour usage in the transportation sector and may define the business cycles in the sector.

2.3 ENERGY SAVING STRATEGIES FOR RAIL TRANSPORT KENYA

In Sub-Saharan Africa, as at the year 2018 only 746km of electrified rail (Addis-Ababa to Djibouti) route. It means the rest of the network uses diesel type of rail making the mode, less competitive as nowadays the requirements in sustainability and emission reduction have caught the eyes of most researchers seeking technical, technological and political solutions. One of the most powerful technological solutions has been replacing conventional vehicles by hybrid and electric vehicles.

Additionally, there have been dramatic developments in rail transport technologies. The most important are (i) very long-life batteries that allow electric trams and trains to operate over substantial distances “off the wire”. [92]–[96] (ii) Charging devices that allow boost battery life by recharging at stops en route – e.g. the super capacitor technology demonstrated at the 2010 Shanghai Expo [97], or the light rail and tram induction system innovative technologies employed by Bombardier. (iii) Discontinuous electrification enabling electric trains and trams to “coast” in areas where would otherwise be prohibitively expensive or impossible to install overhead catenary such as under bridges and through short tunnels.[98]–[101] On the other hand, the researchers and developers should be cautious not to:

- Overestimate the performance of the available battery technologies - research on improvement of battery performance has received a high proportion of attention [102]–[104]. Demonstrated by the number of US Patent and Trademark Office
[105] granted to EU28 on battery technology, fuel cell technology and energy storage technology see Figure 15. However, we should be cautious not to overestimate the performance of the available battery/fuel technologies.

- Omit to account the greenhouse gasses emitted from electric generation - it is crucial to account for the emission from the electrical generation Figure 16. Electric power, according to US data[106] has higher carbon dioxide emissions than other considered sectors, i.e., transportation, industrial, residential and commercial sectors.

Figure 15. Number of units innovations for battery technology, fuel cell technology and energy storage technology

![Number of units innovations for battery technology, fuel cell technology and energy storage technology](image1)

Figure 16. Energy-related carbon dioxide emissions mirroring the trends in energy consumption across cases

![Energy-related carbon dioxide emissions mirroring the trends in energy consumption across cases](image2)

**Specific energy consumption**

The need for efficient and sustainable intracity transportation system has now become indispensable. Electric trains are highly preferred for commuter rail service. However, full railway electrification is often applied to heavily-used routes on which the density of traffic is sufficient to justify the high fixed costs and for developing countries like Kenya, availability of sufficient electricity is a key consideration. Therefore we explore ways to reduce the specific energy consumption of a train.
Passengers railway services are generally classified into three types (i) Urban service characterised by frequent stops, High acceleration and retardation speed (ii) Suburban service characterised by average stops & High acceleration and retardation speed (iii) Long routes service characterised by infrequent stops & high operating speed. Employing the speed/time curve, we can study train movement and energy consumption. Let’s consider a trapezoidal diagram, running and coasting periods of the actual speed/time curve replaced by a constant-speed period.

![Trapezoidal diagram showing acceleration, constant speed and deceleration period](image)

Tractive effort for the propulsion of train if given by $F_a$-Force required to provide a linear acceleration to the traction, $F_g$-Force required to overcome gravitational effect, $F_r$-Force needed to overcome resistance to the motion of the train, $M$ being the dead mass of the train

$$F_t = F_a + F_r$$
$$F_t = F_a \pm F_g + F_r$$
$$F_a = M \propto$$
$$F_a = M_e \propto$$

$M_e$ is (9-15%) of $M$ since a train has rotating mass parts, e.g. wheels, axles, motor armature etc. Converting to absolute figures

$$F_a = (1000M_e) * \frac{1000}{3600} \propto 277.8 \propto M_e, Newtons$$
$$F_g = \frac{M_g * G}{100} = 0.098 * 1000M * G = 98MG, Newtons$$
$$F_r = M * r, Newtons$$
To calculate the specific energy output, we find the total energy output of the driving axles then divide by the product of train mass in tonnes and route length in km.

Therefore, the energy required for train acceleration:

$$E_a = F_a \times \text{area ABE} = 277.8 \propto M_e \times \frac{V_m t_1}{2} = 277.8 \propto M_e \times \left(\frac{V_m^{1000}+V_m}{2+36000+\propto}\right) = 0.01072 \frac{V_m^{1000}+V_m}{M_e}, \text{Joules} \tag{20}$$

The energy required to overcome the gradient

$$E_g = F_g \times D' = 98MG \times \left(\frac{D'}{3600}\right) = 27.25MGD', \text{Joules} \tag{21}$$

The energy required to overcome resistance

$$E_r = f_r \times D' = \frac{D' \times M \times r^{1000}}{3600} = 0.2778MrD', \text{Joules} \tag{22}$$

$V_m$ - Maximum speed (m/s), $D'$ - Total distance over which power remains ON (km), D-distance between stops (km), $M_e$ - efficient mass of train (tonnes), $M$ - dead mass of a train (tonnes), $r$ - specific resistance of the train (newton/ton), $\eta$ - overall efficiency of train components.

The specific energy consumption equation:

$$E_{spec} = \left\{ 0.0172 \times \frac{V_m^{1000}}{\eta \times D} \times \frac{M_e}{M} + 0.2778 \times \frac{r^{1000}}{\eta} \times \frac{D'}{D} \right\}, \text{Wh/t-km} \tag{23}$$

Specific energy consumption is inversely related to distance covered, i.e. the greater the distance covered between stops, the lesser the specific energy consumption. The short distance between stops characterises urban transport thus significantly higher diesel trains GHG emissions.

Taking into account the technology advancements, effortless adaptability of future systems and constrained electrical generation in developing countries, strategies such as the train-tram hybrid that would enable recover energy through regenerative braking (whereby during train braking, kinetic energy dissipated is recovered) and timely maintenance using Hipot device is proposed to improve the overall efficiency of the rail system lowering the specific energy consumption, especially in electro-mechanical components of the system.

According to the demand forecast on major corridors in Nairobi Kenya, i.e., inbound person trips in peak one hour by matatu\(^2\) and bus on 2030 (do nothing case), proved the necessity to plan for mass passenger transport.

\(^2\) A Swahili term referring to a minibus
Figure 18. Person trip by matatu and bus at peak hour (2030, Do nothing case). [107]

Figure 19. Urban Transportation System Selection Chart [107]

From the selection chart, each urban transportation system has a covering range of transportation capacity. If the future demand forecast is close to the maximum capacity of the system, that system should not be selected providing a margin of the capacity. When forecasted PPHPD (Passengers per hour per direction) [107] of a part of the planned corridor exceeds 16,000 in future, BRT (Bus Rapid Transport) cannot be recommended.

The projected future population of Nairobi will exceed 10 million, therefore, in this dissertation, we explore the viability train-tram in hybrid adoption. Germany is a leader in train-tram operations, where infrastructure and rolling stock allows for through running between urban light rail systems and heavy rail. Often referred to as the ‘Karlsruhe Model’[108] after the dual-mode network centred on the city in Baden-Württemberg, Kassel in Hessen state added an extra dimension with the incorporation of diesel-powered vehicles. In September 2007, the tramway/heavy rail link full train-tram working began.

Types of train-tram service:
- Type A train-tram vehicle run on the heavy rail track in mixed operation with conventional heavy rail trains and on the tram tracks in mixed operation with conventional trams. Examples include Karlsruhe and Region Tram Kassel (Germany).
- Type B describes a system in cities without an existing tram network. The train-tram do not run in mixed operation with trams on the centre city network; instead, they run in mixed operation with heavy rail trains on the heavy rail tracks. An example is the Saarbahn in Saarbrücken, Germany.
- Type C includes other systems, for example, those in which the train-tram has its exclusive tracks in the city centre or the regional area and therefore does not run in mixed operation in one or in both of these areas. Examples include the line T4 in Paris and the Randstad Rail in The Hague, Netherlands.

The train-tram hybrid proposed for application in developing countries may be defined as “a railway system that provides a direct connection between its town centre and the regional area of a city. In the city, it runs on electrified tram tracks (partially on-road space) and follows tram regulations. In the region, it runs on conventional (diesel) heavy rail tracks and follows the regulations for heavy rail.” It means that the train-tram vehicles share tracks with trams in the city and with heavy rail trains on the regional tracks with the aim of maximum use of infrastructure [109], [110].

Another important aspect of lowering the specific energy consumption is to increase the overall efficiency of the system. Timely maintenance of electromechanical components of the rail such as motors lowers the tank to wheels losses.

**An automated Hipot (High potential test) rail maintenance device**

Conducting high potential test provides important information about the present and future state of the apparatus (electrical motors, generators, transformers, power cables, electromechanical relays, circuit breakers, etc.) which are all components of a rail system [111], [112]. The key to effective maintenance testing is good data collection. Examining the collected data aids in scheduling diagnostic and repair work, which reduces downtime from unexpected failures[113], [114]. Most electrical machines failure is ascribed to insulation breakdown [112], [115], [116]. As according to a survey of hydro generator failure conducted by Cigre from five different countries showed that insulation damages are the most frequent failures (57%) [93], [117], [118]
Figure 20. Shows insulation damage occurrence accounts for more than half of the sample [117].

Early detection helps mitigate potential failures. High potential test (Hipot) usually is done by manufacturers to obtain dielectric strength data & establish the conformity of the machine to design requirements, (the state of the apparatus and compliance with technological discipline, i.e. IEC, IEEE, NEMA standards [119]–[122]. This thesis encourages scheduled check-ups using the proposed device, though maintenance engineers are hesitant to conduct this test and argue that it causes a significant damage to the insulation system [123], [124] however, so far laboratory research carried out [124] showed no evidence of the test being harmful besides failure of insulation of an electrical machine in transport could lead to huge costs associated with accidents, traffic disruption, outbreak of fire, damage to system in normal operating conditions. The collected data is used to tracks the health condition of the apparatus and when the machine is due for maintenance (e.g. rewinding) or replacement. Hipot should always be conducted after major alterations of an electrical machine such as rewinding, at the maintenance department.

Figure 21. Block diagram proposed for Hipot (High potential test) device
The operator manually connects the apparatuses to be tested to the switching block. When the power is switched on, the program sets the voltage at the output of the high-voltage unit to a test voltage of 1V and runs a continuity test. Further, using a program pre-installed on the computer runs the insulation test. The voltage sensor is used to monitor the voltage from the power source that it does not fall outside the limits of \(+\, -\, 20\%\) of the nominal value. In case the voltage sensor, senses over or under voltage the testing process stops and this is reported to the operator through a sound signal.

The direct current (DC) voltage regulator allows to adjust the voltage value, consists of DC supply E, Transistor Switch K and LC smoothening filter. The Diode allows current to flow through inductance L when switch K opens. The output voltage \(V_{\text{out}}\) is equal to \(V_{\text{avg}}\) determined by the duration of the “ON” key K. In this case, we regulate the \(\tau\) having \(T\) constant, i.e. Pulse Width Modulation (PWM)

\[
\tau = \text{var} \\
T = \text{const.} \\
V_{\text{avg}} = E \frac{\tau}{T}
\]

(24)

To eliminate overvoltages at the output which is typical for pulse voltage regulators with small load currents, the regulator uses an automatic circuit which includes: voltage divider, pulse wave generator, comparator and the differential amplifier.

![Feedback signal](image)

**Figure 22.** The average output of a constant regulator using PWM

\[
\tau = \text{var} \\\nT = \text{const.} \\
V_{\text{avg}} = E \frac{\tau}{T}
\]

(24)

**Figure 23.** The automatic feedback control system
The control system with negative feedback works as follows, block K_1 simulates the operation of differential error amplifier with a coefficient k_1, block K_2 with coefficient k_2 simulates the operation of a comparator producing pulses of duration \( \tau \), block K_3 with coefficient k_3 simulates the operation of the key and the filters producing a constant voltage, depending on the duration of \( \tau \).

The following relations hold:

\[
V_{\text{avg}} = E \frac{\tau}{T_0}, \quad \frac{V_y}{V_{\text{max}}} = \frac{\tau}{T_0}, \quad \tau = \frac{V_y}{V_{\text{max}}} T_0 \quad (25)
\]

\[
V_y = \Delta V * k_y \frac{\tau}{T_0}, \quad \tau = \frac{\Delta V * k_y}{V_{\text{max}}} T_0 \quad (26)
\]

Where \( V_{\text{max}} \) – Amplitude of \( V_{\text{linear}} \); \( V_y \) - input voltage of the comparator; \( k_y \) - a gain of the differential error amplifier (op-amp); \( \Delta V \) is the voltage difference between \( V_y \) and \( V_{vd} \)

It follows that

\[
V_{\text{out}} = E \frac{\Delta V * k_y}{V_{\text{max}}} T_0 = E \frac{\Delta V * k_y}{V_{\text{max}}} \quad (27)
\]

Hence the forward transfer coefficient

\[
k = \frac{V_{\text{out}}}{\Delta V} = \frac{E \Delta V * k_y}{V_{\text{max}}} * \frac{1}{\Delta V} = \frac{E * k_y}{V_{\text{max}}} \quad (28)
\]

In this way, we independently obtain the formula for the forward transfer coefficient for a constant voltage regulator.

Further, \( y = k * \Delta; \Delta = x - x_{fbk}; \Delta_{fbk} = \beta y \)

where \( k \) is the coefficient of transmission (transformation) of the direct circuit; \( \beta \) - coefficient of transmission of the feedback loop, \( x \) - input signal; \( y \) is the output signal.

Implying: \( y = k(x - x_{fbk}); y = (x - \beta y); \ y = kx - k\beta y; \ y + k\beta y = kx \)

Final expression:

\[
y = \frac{k}{1 + k\beta} x = k_{fbk} x \quad (29)
\]

Whereby when,
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 is zero \( \Delta \to 0 \). Giving us a stable system since the error tends zero. Timely maintenance ensures a long time span of the product thus supporting the sustainability of the whole rail system.

2.4 TOTAL IMPACT ANALYSIS

Sustainability has become a top constraint on new technology and system developments over the last two decades. The most widely known definition “Sustainable development is the growth that meets the need of the present without compromising the ability of future generations to meet their own needs” [41]. Here are two essential key-concepts: (i) needs that should be met and (ii) the “idea of limitations imposed by the social organisation and state of technology on the environment's ability to meet present and future needs”. By use of this principle, the analysis and evaluation of the impact of developing new technologies, new technical, technological, social, ecological systems on the environment, safety, security, applied resources, etc. are emerging as essential and required part of feasibility studies, comparison of the available technologies and systems.

Special index for total impact analysis calculated as the total external costs generated by using the transportation system [125]. The developed methodology was used for investigation and comparison of the total impact of conventional and electric cars operating in US and EU [126]

Some thoughts on total impact

Development of sustainable transport is the central element and key objective of vision and programs of the future transport development generally [1], [2], [53]. In efforts to achieve sustainable transport, the numbers researchers in this field are growing exponentially as evident in Figure 24 and also trending within google users
Todd Litman well-known as indicator developer for study sustainable transport [30] defines the goals of sustainable transport from economic (efficient mobility, local economic development, operational efficiency), social (social equity (fairness), human safety and health, affordability, community cohesion, cultural preservation) and environmental (air, noise and water pollution reductions, climate change emissions, resource conversation, open-space preservation, biodiversity protection) point of view. This study adds to this list a further area: governing and good planning.

Other interesting and important study published by Chester and Horvath [127], [128] on investigation the life-cycle energy, greenhouse gas emissions, namely they had taken into account the emissions caused by infrastructure, fuel production, and supply chains. They found, for example, that total life-cycle energy inputs and greenhouse gas emissions contribute an additional 63\% for on the road, 155\% for rail, and 31\% for air systems over vehicle tailpipe operation. The total energy consumption for passenger-km travelled (MJ/pkt) and total greenhouse gas emission in CO\textsubscript{2} equivalent (g CO\textsubscript{2}e/pkt) calculated for rail transport see Figure 25. demonstrating the meaning and major aspects of this approach in impact calculation. As seen, the ratio of operation and total energy consumption and CO\textsubscript{2} equivalent emission of rail transport is small (actually, they are the smallest between the transportation means), because of the required large infrastructure. Another important aspect worth calling to attention is the large differences between rail transport operated in different regions. The CO2e emitted by the Boston light rail rather greater than emitted by light rail operated in San Francisco, because in California 49\% of electricity is fuel-based generated, while in Massachusetts the same ratio reaches the 82\%.

Figure 24. Scientific output indexed by Web of Science and google searches relating to transport impacts (data retrieved on 15/03/2019)
External costs as defined by Bickel and Friedrich, [129] “An external cost arises, when the economic or social activities of one group of persons have an impact on another group, and then that impact is compensated for or not fully accounted, by the first group”. They are usually estimated indirectly using such methods as willingness-to-pay for avoiding, mitigating or controlling particular impacts [130]. Different approaches have been utilised to reduce externalities, for example: using a freight transport model to promote sustainable logistics by simulating the impact use of night freight distribution [131] estimating the emission caused by the vehicle flow [132], and in interrelation of external effects as explained, in case of road congestion and noise, a temporal change of flow, i.e. during off-peak times noise should be reduced by concentrating traffic flow along main roads while during peak times congestion reduction is achieved by shifting transport users to smaller roads [133].

The results of the European and national actions, projects are well summarised and integrated into the reports “External Costs of Transport in Europe” [134], [135], “Handbook on estimation of external costs in the transport sector”[136] and “Update of the Handbook on External Costs of Transport”[137]. The authors of these reports made an arduous work documented by a large number of citations that allows to understand and find the required sources for adaptation of methodology described by this thesis.

**Methodology development**

The total impacts appearing in different forms may be classified into five broad groups:

- safety and security – inducing direct and short time impacts as accidents;
- environmental impacts (chemical emission and noise) – generating direct and indirect, medium and long term impacts on people, nature, living world;
- system peculiarities – system management, management of the transport operation processes, that – for instance - cause the congestions;
The developing and introducing new approach generalises the impact analysis. Firstly, it takes into account all types of impacts (safety, security, environmental impacts, system management, system support, use of resources). Secondly, it summarises all the impacts associated with the use of the transportation systems, e.g. building, operating, recycling of the vehicles, required infrastructure, and applying surveillance and control systems.

This thesis recommends to use a 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):

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

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. [138]

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 optimised 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:

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

where \(i = 1, 2, \ldots n\) defines the different group 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:
\[ TIPi_i = \frac{\sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{u} N_{j,k,q} P_{j,k,q} f_{j,k,q} (l_{j,k,q}) \sum_{v=1}^{u} o_{j,k,q,v} c_{j,k,q,v}}{TLCW_i} \quad \forall i, \]

\[ TLCW_i = \sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{u} N_{j,k,q} W_{j,k,q} \]

where \( j = 1, 2, \ldots m \) depicts the subgroups of impacts, while \( k = 1, 2, \ldots l \) defines the transport means, \( q = 1, 2, \ldots, r \) represents the types or groups of the given transport system, \( v = 1, 2, \ldots, u \) 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 average annual unit, then the \( W \) should be related to the year, too. For instance, if the \( N \) defines the number of vehicle and \( p \) is the annual average running of the vehicles, then the \( W \) equals to \( p \).

The \( p \) parameter acts as the weighting coefficient, or weighting function, too. Of course, it depends on goals and level of studies and on the vehicle or system characteristics, parameters defined by the applied indicators. The consequences, \( o \), namely, the function of consequences, take into account the outcomes the form the impact characterised by the performance indicator. The consequences might be divided into more forms harmonised with the applied impact indicators.

For example, a simple accident may cause damages in (i) vehicle, (ii) transport infrastructure, (iii) buildings, (iv) cultural values, etc. and human casualty might be classified, too, as a fatality, severe and slight injury. The consequences are defined as a function of outcomes because they depend on the level of economy and may change during the life cycle frame.

With taking into account the functions of parameters, impact indicators, consequences and conversation coefficients, the equation (33) can be rewritten in several other forms:

\[ TIPi_i = \frac{\sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{r} N_{j,k,q} f_{j,k,q} (p_{j,k,q}) f_{j,k,q} (l_{j,k,q}) \sum_{v=1}^{u} o_{j,k,q,v} c_{j,k,q,v}}{TLCW_i} \]

\[ TLCW_i = \sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{r} N_{j,k,q} W_{j,k,q} \]

These methods developed for TIPi calculations can be applied to a vehicle, equivalent vehicle, fleet, or the transportation company, transport means, and so on. Therefore, this methodology is structured in a hierarchic form. For example, in very first approximation, the safety impact
of accidents as external costs can be determined by use of the following formula for a light rail company:

\[
TIPI_{safety, accident} = \frac{\sum_{i=1}^{n} N_i p_i I_{sa,i} \sum_{j=1}^{k} o_{i,j} c_{l,j}}{\sum_{i=1}^{n} N_i p_i} = \frac{\sum_{i=1}^{n} N_i p_i I_{sa,i} (o_{d,i} c_{l,d} + o_{i,in} c_{i,in} + o_{i,f} c_{i,f})}{\sum_{i=1}^{n} N_i p_i}
\]  

where \( i = 1, 2, \ldots, n \) defines the type of the light rail at a company, \( N_i \) number of light rail of given type, \( p_i \) is the annual average running of the \( i \) type of light rail, \( I_{sa,i} \) safety accident rate (risk) of the given type of light rails, \( o_{d}, o_{in}, o_{f} \) are the weighting coefficient, namely ratio of damage, injury and fatal accidents by taking into account the third parties involved into accidents. So, the sum of the weighting coefficients as usually is more than 1. Finally, the \( c_{d}, c_{in}, c_{f} \), are the cost conversion coefficients of damage, injuries and fatalities.

**Developing an excel tool for index calculation**

After investigation of the possible use of the developed model, an excel table-model was created. Excel software was considered because it’s a simple, useful tool for statistical analysis when dealing with large data set and was readily available. It is in efforts to create a user-friendly tool. To show application, the tool must adapt to the real calculation by (i) defining the goals, (ii) size and (iii) level of investigation, as well as (iv) possible sources of data, (v) economic and (vi) social conditions.

Principally, all the required information might be defined, derived from the existing statistical data, references, research reports. However, the data very sensitive to the real situations, including the economy, culture, etc. of the region or country investigated. The excel table developed for TIPI calculation and demonstrates its applicability on an example of the TIPIs (TIPIsafety). The describing methodology is based on formulas (34) and (35).

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)

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

  ii. 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 $\text{TIPI}$).

The developing excel table can be used if the parameters, impact indicators, outcomes, etc. will be defined and calculated.
Chapter 3: Developed model testing, applications

3.1 RAILWAY TRANSPORT FORECAST FOR DEVELOPING COUNTRIES

Major factors affecting the future development of rail transport identified in this thesis include:

Technical, technological aspects

Technical development depends on the interaction of three groups of factors:

- development of sciences and technologies,
- the appearance of new rail with better performances and
- development of the infrastructure.

The technology developments are catalysed by

- the information technology,
- the industry 4.0 revolutions,
- the material sciences,
- the application of advanced systems (structures, controls) based on biological analogy,
- the extensive use of micro-sensors and actuators and
- the appearance of new solutions (electric and train-tram hybrid systems, magnetic levitation & Hyperloop trains).

Scientific and technology developments follow special laws and models. For example, the info-communication revolution-following to Holmes opinion [139] characterised by the following major rules and observations:

- Moore’s law (every 18 months computing power doubles),
- Gilder’s Law (communication power doubles every 6 months),
- Metcalfe’s Law (network value is proportional to the square of each terminal’s processing power),
- the unwritten law of abundance (wasting which is in abundance to solve human problems),
- the unwritten rule of gridlock (the added highway lane miles create more demand than they are designed to relieve),
- Kurzweil’s Law of Accelerating Returns (in the next decade more technology is developed than in the past century),
- the Golden Rule of the information age („time is gold”).

These major factors defining the possible development of the new technologies including, for example, better infrastructure simulation and design, optimisation of forms, distributed
elements, new rail supporting systems - Internet of things is opening new possibilities for obstacle and damage detection, preventive maintenance, linkages with other systems, Operational concepts - Revolutionary communications ,( LTE - Long-Term Evolution, 5G), and cloud infrastructure (backend) offers attractive solutions for handling large volumes of data and avoiding bulky rail-side infrastructure etc.

**Economic aspects**

The economic aspects and their development level are estimated with three main types of indicators: (i) leading indicators (new orders for consumer durables, net business formation, and share prices) that attempt to predict the economy's direction, (ii) coincident indicators (GDP - gross domestic product, employment, unemployment rates, retail sales) that shows up together with the occurrence of the associated economic activity, and (iii) lagging indicators (GNP - gross national product, consumer price index, interest rates) that become apparent only after the occurrence of the associated economic activity.

Most forecasts use the merit of economic development, GDP, as the major driver determining the future demand of various transportation systems. Numerous highly cited and applied investigations demonstrate the clear interconnection between the GDP and rail transportation growth see Figure 6. Other major economic events include fuel price increases, wars, large terror actions, or bird flu have serious influences.

Rail transport highly depends on the economic developments level of a country/ region, its dependencies may be identified by other economic indicators such as net incomes, unemployment rate, or globalisation level. Globalisation is a way of economic developments, it started by the globalisation of the production and product distribution processes, but it expanded to the globalisation of education, research and development, culture and even roles in societies.

The globalisation factor drives the modern economy, the extensive distribution of the industry at country or even continent levels, being supported by huge supply chains that catalyse the growth of rail transport system to cater for the demand within and across the border.

**Societal (mobility) factors - change in societies**

The economic developments and people’s free motion result in changes in societies and mostly in mobility. Mobility is determined by numerous factors, which could be classified into the following three categories [140]:

- demographic factors – e.g. population, age, genders, occupation
- socio-economic determinants – e.g. GDP, job opportunities, household-level net income, electricity per capita
- transport accessibility and affordability – e.g. infrastructure, service provision, price, speed.

The societal factors can be represented by the population, population density (number of people living on a unit area of land), population of active ages (% of the population aged between 25 – 56), education level (% of the population with high-level education), unemployment rates, urbanisation (as % of the population living in urban areas), household (net) income, or GINI. GINI (introduced by the Italian statistician and sociologist Corrado Gini) measures the inequality in people incomes. Mathematically, based on the Lorenz curve, which plots the proportion of the total income of the population (y-axis) in the function of the total share of people from the lowest to the highest income (Figure 26).

![Lorenz curve diagram](image)

**Figure 26.** Determination of the GINI coefficient (index) as the ratio of the areas related to A/(A+B)

The Gini index is not often used but a rather interesting indicator. It often changes by a way that is not so simple to understand and not so clear. For example, Figure 27 shows that the GINI index of Spain is increasing and according to the simple autoregressive forecast it will be increased in future, too. Meaning, the inequality in personal or household incomes is continuously growing in Spain. The reason might be caused by changes in the taxation system, economical deep long-continued crisis, “economic colonisation”, etc. It is rather interesting because Spain is a well-developed country that “should” have better equality in people incomes. On the other hand, changes in Poland Gini index (Figure. 27 bottom figure) describes the excellent development of Poland closing to better income equality of developed countries.
Figure 27. Changes in Gini index of Spain and Poland (input source: Knoema after WDI)

Figure 28 demonstrates that there are adequate inputs also to study and forecast the population density. However, there is no reliable information about the effects of migration on the population. In EU countries, the population growth might be catalysed by migration. That means a large ratio of population in a period of integration into the society and economy and have lesser incomes and therefore more likely to use public transport (rail).

Figure 28. Population forecast by use of autoregression models (Input source: Knoema and United Nations Department of Economic and Social Affairs)
DEVELOPED FORECASTING METHODOLOGY

Figure 29 shows the methodology developed for the rail transport forecast to investigate the adoption and future rail transport of systems in developing countries. The methodology contains four major cycles:

*Concept development*

- definition of the objectives (develop tools for support railway strategic management),
- study the requirements (requirements supporting or hindering the rail transport systems advancement with focus on Africa),
- investigation of the available forecasting methods (references),
- study the available software-based forecasting supports. (e.g. MATLAB),
- analysis and evaluation of the data sources (here: OECD - The Organisation for Economic Co-operation and Development, Knoema - World Data Atlas, African Development Bank, World Bank Development Indicators, etc)
- the data sources and availability of the supports (software) should be evaluated from the usable point of inputs (namely economic, societal, technical, technological, etc. drivers);

*preliminary actions*

- situation analysis: technology foresight analysis and evaluation, demand, affordability
- drivers’ handling: identification, analysis and selection of the drivers (future forecasting) and definition of dummies.
- predefinitions and classifications: rail classification (depending on their characteristics and performances as diesel, electric, hybrid, high-speed rail, geographical sectoring, demand generation value defined for region levels for data harmonisation region) and economic cycle study [141] and definitions;

*medium-term forecast:*

- first step: driver forecast (using the AR - autoregressive models and/or available forecasts (like GDP), rail passenger forecast on regional level using the non-linear ARX (autoregressive with exogenous terms) models and analysis and harmonisation of the results,
- second step: improving and tuning the models by using the predefined dummies, economic cycles and converting the results to the passenger-km (pass-km) demand (by predefined travel distance depending on the rail characteristics and regions);

*long term forecast:*
third step forecast: using the dummies predefined for longer terms, applying the „S” – curve of innovation diffusion process (representing by Gompertz curve) and analysis and harmonisation results,

- tuning: taking into account the generalised rail cost, door-to-door speed, cost, time, and travelling budget (travel expenditure from income).

The methodology includes evaluations and harmonisation of results between the major cycles. It implies that the results must be evaluated together with the stakeholders. Three groups of dummies could be identified that define the changes the indicators caused by different events:

- introduction of new revolutionary new technologies, with considerably improved performance,
- a step-change in the infrastructure (new high-speed train being open in the given region, or special program to develop the railway system),
- other demographic, or cultural events (e.g. the introduction of new tourist attraction).

This thesis identifies three relevant dummies (i) Standard railway gauge phase one implementation in the year 2018 (ii) Nairobi to Malaba with connectivity to Kisumu, Uganda and Rwanda (phase 2) Opening to landlocked countries, 2021 (iii) 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. It is clear that dummies must be identified, analysed and selected for each region and countries individually.
Simulation and results

The methodology has been adapted to the forecasting of demand-accessibility of rail transport.
Chapter 3: Developed model testing, applications

Figure 30. Forecasting the GDP of selected countries by using different models

As can be seen, the different models result in considerable different forecasted time-series (Figure 30). Applying the same models, the findings are confirmed by a comparison analysis (Figure 31). Such an approach can be useful to find a pattern in the data series. The time legs too may contain similarities between the regions or countries development.

Figure 31. Comparison of the forecasted GDP of different countries

As can be seen, unique and well-applicable methods which yield the same results are not available. Usually, the forecast contains some effect of ‘art’ (subjective factors of the forecasters).

The developed and applied method has sensitivity to inadequate input data. There were huge series of simulations performed without possible identification of the problems caused by
incorrect and/or incomplete data. For example, in some cases, the results look good (Figure 32 & 33), while in other cases, the forecast is incorrect (Figure 34 & 35). These figures illustrate why the methodology contains relevant harmonisation sections.

Figure 32. A forecast of China, looking good as is expected

Figure 33. A forecast of India with acceptable results
Figure 34. A wrong forecast results of Russia

Figure 35. Unacceptable forecast results of Japan
Figure 36. A forecast with constrained education drivers, but acceptable results

The figures 37, 38 & 39 show interesting and limiting part of rail transport forecast for African regions. As earlier stated, the majority of Africa’s rail is worn out and have been on a decline; thus passengers-km carried & ton-km of freight transported forecasts zero.

Figure 37. A forecast of Ghanaian data
Figure 38. A Rail passenger demand-accessibility forecast for Kenya

Figure 39. Rail freight demand-accessibility forecast for Kenya
Figure 40. Results for freight (upper) & Passenger (lower) harmonized demand estimation for Kenya

Figure 41. Concept validation using Japan historical data

3.2 ECONOMIC DEVELOPMENTS SUPPORTED BY RAILWAY TRANSPORT

According to European statistics [142], the transport volume depends on the economy level (Figure 42). The graph is quite similar to Figure 10. As can be seen, freight transport has a higher sensitivity to changes in GDP. It is well understandable because the transport of goods depends on the production process intensity and market pull effects that are decreasing in the case of economic crises.
Figure 42. The economy and transport interaction (passenger-km includes all types of the passenger transport: passenger cars, powered two-wheelers, buses and coaches, tram and metro, railways, intra-EU air, intra-EU sea; transport of goods including the road, rail, inland waterways, oil pipelines, intra-EU air, intra-EU sea transport, GDP defined at constant year 2000 prices and exchange rates)

The correlation coefficient of GDP and different transport indicators (Table 4.) shows an interesting aspect of the interaction of GDP and transport volumes. The rapidly developing countries India and China characterised by high railway utilisation of railway for both freight and passengers’ volumes. Well developed countries for this case the United States and Germany GDP changes well correlates with the rail transport volumes. While moderately developing countries, i.e. Kenya and Tanzania rail transport volumes do not correlate with GDP changes [143]

Table 4. 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>-0.10499</td>
<td>-0.37425</td>
</tr>
<tr>
<td>Tanzania</td>
<td>-0.46571</td>
<td>-0.71696</td>
</tr>
<tr>
<td>India</td>
<td>0.96861</td>
<td>0.98576</td>
</tr>
<tr>
<td>China</td>
<td>0.78605</td>
<td>0.841281</td>
</tr>
<tr>
<td>Japan</td>
<td>-0.32059</td>
<td>0.696024</td>
</tr>
<tr>
<td>France</td>
<td>-0.88354</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>

Different rail transport systems depend on the economic practices of a country/region, in the sense that a resource extraction and manufacturing sectors rely heavily on freight rail while a service economy (advanced manufacturing, distribution services) tends towards the efficiency of logistics and urban transportation & there’s the mixed economy as well.
India tops as the country by passengers carried by railways in the world as at 2017, passengers carried by railways in India was 1,149,835 million passengers - km accounting for 44.56% of the world’s passengers carried by railways. The top 5 countries (others are China, Japan, Russian Federation and Germany) account for 86.53%. The world’s total passenger carried by railways estimated at 2,580,373 million passengers - km in 2017.

On the other hand, the Russian Federation is the top country by goods transported by railways in the world. As of 2017, goods transported by railways in the Russian Federation was 2,491,876 million ton-km that accounts for 29.54% of the world’s goods transported by railways. The top 5 countries (others include: United States, China, India, and Kazakhstan) account for 93.75% of it. The world’s total goods transported by railways estimated at 8,436,927 million ton-km in 2017.

Another aspect investigated was the interaction between the technology development and business cycles. This aspect had been studied by the Schumpeter already. He drew the
innovation cycle Figure 45 that a slightly different from the Kondratieff waves (Figure 14). The difference is characterised by reducing the cycles period. This effect is harmonising with the Kurzweil’s law of accelerating returns. As Kurzweil [144] defined “The Law of Accelerating Returns”, the rate of changes in a wide variety of evolutionary systems tends to increase exponentially (including but not limited to the growth of technologies).

Figure 45. The Schumpeterian cycles of innovation and entrepreneurship

The innovation cycles have direct interaction with the development of the vehicles and transportation systems, like railway, internal combustion engine, aviation, e-mobility. The speed of rail constitutes evidence of technological development and linkable to the innovation cycle. After the success of the Shinkansen operations, technological progress in several European countries, particularly Germany, Italy, France, and the UK, developed new technologies and innovations aimed to establish the basis for the "passenger railway of the future." However, the difference in the shifting of economic cycles depend on the regions is not connected with high-speed train development

Figure 46. High-speed rail history
INTERACTION BETWEEN THE ECONOMY DEVELOPMENTS AND TRANSPORTATION SYSTEMS

There is not a unique and standardised method for dating the business cycle. Probably, the most used cycle definition results are the NBER business cycle. NBER-National Bureau of Economic Research as read on its website [145] is “private, non-profit, non-partisan research organisation's main aim is to promote greater understanding of how the economy works”. This organisation uses a sophisticated approach to business cycle dating based not only on GDP and GDI (Gross Domestic Income as income received by all sectors of an economy within a state) but on using a range of other indicator characterising the (domestic) economy. Principally NBER evaluates the significant decline in economic activity defined by monthly indicators. The NBER business cycle for period 1854 – 2009 are defined in Table 5.

Table 5. NBER cycles since 1960

<table>
<thead>
<tr>
<th>Peak month</th>
<th>Trough month</th>
<th>Peak month number</th>
<th>Trough month number</th>
<th>Duration, peak to trough</th>
<th>Duration, trough to peak</th>
<th>Duration, peak to peak</th>
<th>Duration, trough to trough</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 1960</td>
<td>February 1961</td>
<td>1924</td>
<td>1934</td>
<td>10</td>
<td>24</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>December 1969</td>
<td>November 1970</td>
<td>2040</td>
<td>2051</td>
<td>11</td>
<td>106</td>
<td>116</td>
<td>117</td>
</tr>
<tr>
<td>November 1973</td>
<td>March 1975</td>
<td>2087</td>
<td>2103</td>
<td>16</td>
<td>36</td>
<td>47</td>
<td>52</td>
</tr>
<tr>
<td>January 1980</td>
<td>July 1980</td>
<td>2161</td>
<td>2167</td>
<td>6</td>
<td>58</td>
<td>74</td>
<td>64</td>
</tr>
<tr>
<td>July 1981</td>
<td>November 1982</td>
<td>2179</td>
<td>2195</td>
<td>16</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>July 1990</td>
<td>March 1991</td>
<td>2287</td>
<td>2295</td>
<td>8</td>
<td>92</td>
<td>108</td>
<td>100</td>
</tr>
<tr>
<td>March 2001</td>
<td>November 2001</td>
<td>2415</td>
<td>2423</td>
<td>8</td>
<td>120</td>
<td>128</td>
<td>128</td>
</tr>
<tr>
<td>December 2007</td>
<td>June 2009</td>
<td>2496</td>
<td>2514</td>
<td>18</td>
<td>73</td>
<td>81</td>
<td>91</td>
</tr>
</tbody>
</table>

| 1854-2009 (33 cycles) | 17.5 | 38.7 | 56.4 | 56.2 |
| 1854-1919 (16 cycles) | 21.6 | 26.6 | 48.9 | 48.2 |
| 1919-1945 (6 cycles) | 18.2 | 35.0 | 53.0 | 53.2 |
| 1945-2009 (11 cycles) | 11.1 | 58.4 | 68.5 | 69.5 |

Note: Month numbers started in January 1800

Figure 47 shows the NBER business cycle between 1960-2009 as NBER recession periods. As illustrated, the US YoY-ROC GDP (year-over-year rate of change in GDP) – defined by a plot published by [146]– and the US GDP rate of changes (red curve) – determined from the real GDP that chain-weighted based in billion real 2010 USD provided by the Global Insight – both interact with the economic recessions.
Chapter 3: Developed model testing, applications

Figure 47. The economic recessions identified by NBER on the time histories of YoY-ROC GDP [146] (from and the GDP (red line) provided by Global Insight

Of course, there are several other methods for study and determining the business cycles from the series of economic data [147], [148]. In transport sector economic cycles analysis, probably the methods using the Markov-switching models [149],[150],[151] may result to the best solutions, but the data are limited to mainly yearly.

Figure 48 illustrates that the economic developments of countries are somewhat different. For example, China does follow to NBER dated recessions, while Russia had a crisis after 1988 catalysed by the political change.

Figure 48. GDP rate of different countries (determined from Global Insight data) and the NBER recession periods (light brown rectangles)

These Figures 49 and 50 explains why forecasts of economic cycles are incredibly complex and cannot be simply predicted. The analogy in the changes of the economic developments measured by the GDP, as shown in Figure 49 (a gap between the well and less developed countries), allows using the historical data of well-developed countries.
Figure 49. Real economy developments of selected countries (a) and curves “dated back” for Hungary and Poland (b) (used input source: WDI)
Dating back’ economic developments for selected Sub-Sahara countries shows they are about 50% lagging figure 50. In any case, the good solutions need accurate, probably monthly and several indicators. Unfortunately, such time series for the rail transport sector is available in somewhat limited forms. Another important fact is that the political changes have significant influences on the economic developments of developing economies (like Kenya) and newly democratic countries (see the early 1990s in Figure 10. during the introduction of the multi-party system in Kenya).

There is an interesting scenario with time-series data, which varies depending on the source, and such aspects introduce difficulties and barriers in the evaluation of interrelationship between the economy and transport sector. I have applied processes of analogy (of changes in the economy and transport sector) and applied the methods of statistics (autocorrelation, correlation) and methods of time series analysis available in Matlab. See also the effect of railway transport developments on the economy[141]. Our results well harmonised with the results of [91] while they had investigated the interrelationship of transport and aggregate economy (based on USD data).

At the very first glance of Africa Rail (Figure 1) the technology in use is very old and not environmental friendly. This explains why despite being a hub of raw materials and having high passengers’ demand, it has continued to lag as compared to the rest of the World.
3.3 APPLICABILITY OF ENERGY SAVING STRATEGIES FOR KENYA RAIL SYSTEM (DEVELOPING COUNTRIES)

The technology identification, evaluation and selection (TIES) is a large set of procedures that could be applied in task, goal and objective oriented individual processes. There is no unique solution, each case requires a special approach. All the processes starting with brainstorming and definition of the rules, procedures might be and should be applied. There are several theories like defined by [152], but no one for general use. Even, the technology evaluation depends on changes in governing rules and paradigms. So, it is important to understand the paradigm changes that underpin the development of the new product.

In many cases, the technology evaluation is started by management and societal aspects. For example in[153], professor Bakouros described the utilization of many different tools such as brainstorming, Delphi method, idea advocate, creativity assessment, cluster analysis, dendrogram, matrix data analysis, factor analysis, opportunity analysis and reverse brainstorming that could be applied together in process of a technology evaluation. Kirby had made more clear the TIES in his PhD thesis[154] (Figure 51).

There are 8 steps should be applied in the iteration process:

- Problem definition: actuality, problem to be solved, costumer requirements, expected budget (or benefits), possible scheduling, etc. – like solving the noise and emission problems, and transport efficiency.
- Concept space definition: applying the morphological matrix (using in analysis of multi-dimensional, non-quantifiable problems by filling up a matrix with columns of different possible solutions and rows of system features, systems elements and quantitative evaluation criteria), analysis of alternative concepts, definition of the design spaces - with use of such features as effects on the required changes in rail infrastructures, rail operations, required investment, benefits, society expectation, society acceptation, and so on.
- Modeling and simulations: starting from visual and verbal models help in understanding the developing concepts, through simulations based on physical principles, up to the stochastic (like Monte Carlo) models and simulations catalysing the definition and evaluation of the system constraints, limitations, levels of confidences, developing and using the response system equations describing the relationships between several explanatory and response variables, etc.
- Investigation of the design space: based on deterministic and stochastic analysis, investigation of the sensitivity functions, effects on changes in metrics on the
design spaces, use of probability density functions, fast probability integrations, etc. methods combining with stochastic simulations.

iv. Evaluation of the system feasibility: for defining the constraints and system feasibilities needing improvements.

v. Technology identification: defining those technologies that may perform the required system features; using the technology compatibility and impact matrices - that may play more important roles in case of identification of radically new technologies and developing the disruptive technologies.

vi. Technology evaluation: that is based on the technology forecast, appearing and technology forecast of appearing and emerging new technologies, physical aspects of technology application, decision making.

vii. Technology selection: multi-criteria, multi-attribute decision making with the use of special methods as genetic algorithm, evolutionary and revolutionary techniques, combining with resource allocation, etc.

Of course, all the technology and product development needs own approach to TIES depending on resources, required changes in existing systems, society acceptances, etc.

**Train-tram hybrid concept space definition**

Train-tram model is cost-effective for Nations looking to expand existing rail networks, those with electrified urban rail and non-electrified rural network conditions and those that are
building rail network from scratch could benefit from exclusively type C. We have adapted Europe studies ‘checklist for successful application of train-tram systems in Europe’ [155] to check applicability to Kenya’s needs and possibilities.

**City and region Characteristics**

(i) City scale and region metropolitan area - Homer Hoyt’s sector theory of Urban Development [46] and Ernest Burgess’ concentric zone theory [47] highlight cities growing outward from (the Central Business District) a core district towards the periphery with distinct land use zones. However, the majority of developing countries cities run the risk of growing too far out (Urban Sprawl). (ii) Hand in hand with population density and accessibility (ii) All cities and region development theories supports a type of layout settlement – the existence of the main activity centre and other smaller businesses along the line, (iii) In consideration as well should be the distance between the railway station and business centre. (iv) The type of tramway corridor in operation (which in SSA is almost non-existent) (v) Conversion of a corridor (monument conservation, national parks) [155]

**Infrastructure and Technical Parameters**

(i) Adequate corridors – elementary features for a power system change area presents an opportunity as in SSA countries are still at the drawing board thus can conform to standard type for the entire region. (ii) Technical parameters of the existing tram (gauge) (see figure 1). Most of the meter gauge rail in Africa, is worn out and beyond repair [21] (iii) Essentially joining up the tram and heavy rail so that local services sharing paths with conventional trains on the mainline can travel over both systems, thereby facilitating seamless journeys and accessibility, attention should be paid to platform heights (tram–heavy rail) complexity for handicapped accessibility (iv) Heavy rail tracks technical parameters of the (equipment, decision between special rolling stock or track transformation)

**Existing Connections**

(i) Existing connections (status, performance, travel time, comparisons), for SSA region except for Ethiopia, the whole region is running on underperforming diesel train enhancing (ii) circumstances for the demand of tram-train hybrid. Also contributing to the non-electrified rail is the limited electric generation in this region, furthering the diesel train era; thus, a hybrid system is a necessity. (iii) Capacity on the tracks with today’s connections – The SSA rail lines (total route-km) fluctuated substantially in recent years and tended to decrease through 1997 - 2016 period ending at 59,634 km in 2016 [4]. (iv) Capacity on the crossroads–stations with today’s connections.
Institutional Circumstances

The (i) position of the railway–tram companies (financial conditions, organisational and management structure) plays a significant role as (ii) the cooperation between the City-regional system is significant for the system since their efficiency is as swift as their partnership. (iii) City’s policy-strategy, decision-makers influence the progression or cancellation of new projects and their planning framework. (iv) Country and region economic conditions (v) regulatory conditions (vi) and status of state adverse projects (financial support).

Table 6. 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>
</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>
<td>e-mobility</td>
</tr>
<tr>
<td></td>
<td>More than 50% renewable</td>
<td>Electrified infrastructure</td>
<td>Average population</td>
<td>Well capacity utilisation</td>
<td>No existing network</td>
<td>Electric trains</td>
<td>Charging station</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diesel-electric trains</td>
<td>Regenerative braking</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Train-Tram hybrid</td>
</tr>
</tbody>
</table>

The morphological matrix was applied to illustrate the features available, and that contributes to the train-tram hybrid being the ‘most suitable system solution’ for developing countries with respect to 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.

Following the Hipot device demonstrating the importance of real engineering and scientific study, the system element might, we investigate the effect of load change to demonstrate what happens when an electrical device has faulty insulation. Figure 52 shows the possibility to conduct qualitative tests for several apparatus in the shortest time possible. In the circuit, a voltage and current sensors are connected to measure the signals and in case of ‘failed tests’ informs the operator through a sound/light output.
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 \( (V_{vd} - V_{d_{ac}}) \) \( K_{op-amp} \).

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 \( (V_{vd} - V_{d_{ac}}) \) \( K_{op-amp} \). At the beginning of each period T Switch S1 is closed and when \( V_{wave}(t) \) reaches the value \( V_{vd} - V_{d_{ac}} \), 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 54 oscillogram shows when the signal after connecting and disconnecting the load $R_n = 100$ Ohm at the output of the automatic regulator.

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 the surge occurs and a test fail is registered. The time to set the output voltage when the load is connected is about 5 periods of frequency 10 kHz, which is much less than the period of the sinusoidal output voltage of the inverter.

**Hipot pass**: Able to withstand the high voltage and does not breakdown or does not allow excess leakage current to flow on the surface of the product under test.

**Hipot fail**: Excessive leakage to the chassis of the device under test

According to standard, the test voltage should be twice the nominal voltage plus 1000V. The proposed device delivers up to 3kV, it also performs ‘continuity test’ voltage of 1v and checks voltage limits from mains, if within +/- 20% of nominal value.
Insulation of any electrical device 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.), routine check helps obtain statistical information about its health and defects are detected early. This way, the efficiency of the electrical apparatuses such as motor increases, thus enhancing overall the performance of rail by reducing $I^2R$ losses.

Inverse power-law model may be used to evaluate electrical insulation and dielectrics (voltage endurance) given by the formula:

$$\frac{\text{Time}_{\text{norm}}}{\text{Time}_{\text{acc}}} = \left(\frac{\text{Voltage Stress}_{\text{acc}}}{\text{Voltage Stress}_{\text{norm}}}\right)^N \quad (36)$$

Where: Time is a function of any given voltage stress, Time$_{\text{norm}}$ = Time at normal stress, Time$_{\text{acc}}$ = life at accelerated voltage stress, Voltage stress$_{\text{norm}}$ = normal voltage stress, Voltage stress$_{\text{acc}}$ = accelerated voltage stress, N = acceleration/environmental factor

The results may be used to plot a graph that would help in scheduling maintenance reducing $I^2R$ losses of energy to the chassis inform of heat.

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.

### 3.4 ANALYSIS OF IMPACTS FOR RAIL MODE OF TRANSPORT

**Investigation of the accident outcomes**

The consequences, as outcomes of traffic accidents, might be defined relatively easy, while calculation of the costs associated by these outcomes is a sufficiently more complex and hard problem.

The accident consequences may be classified into three groups:

- human injuries, namely fatality, severe injury and slight injury,
- damages including the damages in cars, in transport infrastructures, as road structural damages, damages in traffic control systems, losses of products or production capacity (for example due to damage the electric supporting system, damage of production supplying materials) and other damages like damages inbuilt (houses, electric lines, etc.) and nature environments, cultural heritages,
- societal consequences as, cost of accident investigation medical costs, administrative and juridical processes’ costs, traffic congestions, extra expenditure of relatives and friends of the injured people.
Here some thoughts about the estimation of the costs associated with human injuries. There is a covenant in references; the injuries are classified as a fatality, severe and slight injuries. Probably the most common and well used [127], [129]–[134], [136], [137], [156] definition:

- **Fatality**: death during the accident or within 30 days after an accident.
- **Serious injury**: casualties require hospital treatments and have lasting injuries.
- **Slight injury**: casualties do not require hospital treatment or only a short staying in hospitals.
- **Damage-only accident**: accident without casualties.

The Commission Directive [157] defines the conventional safety indicators (for railway transport) and common methods of calculating accident costs. For example, it introduces the following indicators to calculate the economic impact of accidents as total in euro and relative (to train-kilometres):

- number of serious injuries and deaths multiplied by the Value of Preventing a Casualty (VPC),
- cost of damages to the environment,
- cost of material damages to infrastructure/rolling stock
- cost of delay as a consequence of accidents.

The Commission Directive [157] state on that, the “The economic impact of major accidents shall be reported by the security authorities. The VPC is the value society assigns to the mitigation of a tragedy and as such does not constitute a basis for compensation between accident parties.”

The Commission Directive [157] defines the other relevant indicators and terms, too. For instance, the “significant damage to stock, track, other installations or environment” means damage that is equivalent to EUR 150 000 or more; or “extensive disruptions to traffic” means that train services on the main railway line are suspended for six hours or more.

The costs associated with transport accidents might be estimated by Value of Preventing a Casualty (VPC). The Commission Directive [157] states the VPC is composed of

- value of safety per se: that can be estimated by Willingness to Pay (WTP) values,
- direct and indirect economic costs containing the (i) medical and rehabilitation costs, (ii) legal court cost, private crash investigations, cost for police, the emergency service and administrative costs of insurance, and (iii) production losses: value to society of services and goods that could have been produced by the person if the accident had not occurred.
This approach is well similar with methodology applied by the European international studies [127], [129], [130], [132]–[137], [156]. One of the latest excellent cost estimation [137] uses the following costs are related to the accident risk:

- expected cost (of death and injury) due to an accident for the person exposed to risk,
- expected costs for the relatives and friends of the person exposed to risk,
- accident cost for the rest of the society (output loss, material costs, police and medical costs).

These costs can be determined even for risk of each vehicle and road types with taking into account the traffic flow intensity and internal costs.

The costs related to death as a cost for relatives and friends as usually are estimated by use of the Willingness to Pay method [158] See Table 7. The costs of fatalities that the people willing to pay for avoiding fatal accidents are not harmonised with the net income of people or GDP per capita (Figure 55).

Table 7. Some economic drivers and estimated values for casualties avoided [3], [137] for the year 2010

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Latvia</td>
<td>10743</td>
<td>8779</td>
<td>35.27</td>
<td>1034000</td>
<td>140000</td>
<td>10000</td>
</tr>
<tr>
<td>Estonia</td>
<td>14062</td>
<td>10683</td>
<td>32.16</td>
<td>1163000</td>
<td>155800</td>
<td>11200</td>
</tr>
<tr>
<td>Slovakia</td>
<td>16062</td>
<td>10897</td>
<td>24.94</td>
<td>1593000</td>
<td>219700</td>
<td>15700</td>
</tr>
<tr>
<td>Slovenia</td>
<td>22942</td>
<td>21572</td>
<td>35.79</td>
<td>1989000</td>
<td>258300</td>
<td>18900</td>
</tr>
<tr>
<td>Greece</td>
<td>25851</td>
<td>21382</td>
<td>34.48</td>
<td>1518000</td>
<td>198400</td>
<td>15100</td>
</tr>
<tr>
<td>Spain</td>
<td>29956</td>
<td>27052</td>
<td>26.81</td>
<td>1913000</td>
<td>237800</td>
<td>17900</td>
</tr>
<tr>
<td>Italy</td>
<td>33761</td>
<td>27809</td>
<td>34.41</td>
<td>1916000</td>
<td>246200</td>
<td>18800</td>
</tr>
<tr>
<td>France</td>
<td>39186</td>
<td>33892</td>
<td>33.78</td>
<td>2070000</td>
<td>289200</td>
<td>21600</td>
</tr>
<tr>
<td>Germany</td>
<td>40164</td>
<td>32754</td>
<td>31.14</td>
<td>2220000</td>
<td>307100</td>
<td>24800</td>
</tr>
<tr>
<td>Belgium</td>
<td>43000</td>
<td>38879</td>
<td>28.53</td>
<td>2178000</td>
<td>330400</td>
<td>21300</td>
</tr>
<tr>
<td>Finland</td>
<td>43864</td>
<td>36693</td>
<td>27.74</td>
<td>2213000</td>
<td>294300</td>
<td>22000</td>
</tr>
<tr>
<td>Austria</td>
<td>44916</td>
<td>36416</td>
<td>30.25</td>
<td>2395000</td>
<td>327000</td>
<td>25800</td>
</tr>
<tr>
<td>Ireland</td>
<td>46019</td>
<td>46917</td>
<td>32.3</td>
<td>2412000</td>
<td>305600</td>
<td>23300</td>
</tr>
<tr>
<td>Netherlands</td>
<td>46623</td>
<td>42711</td>
<td>28.73</td>
<td>2388000</td>
<td>316400</td>
<td>25500</td>
</tr>
</tbody>
</table>
It hasn’t been identified any economic drivers that might be applied for determining the values of accident fatality avoidance or as referred to us the value of statistical life. On the other hand, the fatality cost reaches the net income owned for 70 up to 200 years. People with smaller incomes willing to pay a more considerable sum for their life. It is interesting; the willingness is somewhat higher in the case of countries having less GDP. It seems the fatality costs are overestimated. The people are willing to pay money that they have not in their hand. Another interesting question, Are the people travelling as usually by train or people using their car willing to pay the same amount of money for avoiding the fatal accident?

This thesis used the adapted costs that were determined from Table 7. The values were increased proportionally with GDP growth and corrected by the dynamics of changes in net incomes using the model from [125]. It 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.
It wouldn’t be justifiable to compare TIPI for different countries because the cost conversion is not standardised and rather depends on the country’s economy. However, though Germany has a higher willingness to pay to avoid casualties their safety index in terms of rail accidents is visibly higher than other EU selected countries.

There were classified ‘others’ accidents risks; this may include the effect of congestion on the accident risks [159] and delay in travels because of the accidents or congestions initiated by accidents which are recommended to include in the accident's consequences. It might be calculated as the number of people and cars affected by the traffic flow reduction and delays multiple by increased travel time and people value of time and cars’ operating costs (separately).

**Investigation of emissions from urban rail transport**

For the calculation of greenhouse gas emissions (GHG) standard considers, the unit of CO2e (carbon dioxide equivalent) as carbon dioxide represents the largest share of the production of greenhouse gases. CO2e value indicates the influence of each greenhouse gas on global warming using the conversion amount or concentration of CO2, which would have similar effects. Direct emissions are dependent on the type of vehicle, the load, the distance and the amount of fuel used while the production of power and fuels, the manufacture of vehicles, the maintenance of the transport network and construction of streets also use energy and cause greenhouse gases consists of the indirect emissions. When producing the carbon inventory for logistics services, indirect emissions from the production of fuels play an important role. For example, for diesel, all emissions – from the extraction of the crude oil via its transport to the refinery, the actual distillation of the diesel and its transport to the filling station- have to be
included. For electrically operated modes of transport such as trains, the carbon footprint requires information on the generation of the necessary power.

Definitions of energy consumption and emissions following EN 16258

- Well-to-tank (WTT) (energy processes): Recording energy consumption and all indirect emissions from fuel provision from the well to the vehicle tank. Energy consumption includes losses during the production of the energy sources e.g. in high-voltage lines.
- Tank-to-wheels (TTW) (vehicle processes): Recording all direct emissions from vehicle operation. Consumption here refers to as final energy consumption.
- Well-to-wheels (WTW) (vehicle and energy processes): The sum of well-to-tank and tank-to-wheels, i.e. direct and indirect emissions. Consumption here refers to as primary energy consumption which, besides the end, energy consumption, includes all losses from the upstream chain.

Table 8. Factors for the calculation of energy consumption and greenhouse gas emissions (calculated as CO2 equivalents) following EN 16258

<table>
<thead>
<tr>
<th></th>
<th>Standardised energy consumption</th>
<th>Greenhouse gas emissions (calculated as CO2 equivalents)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tanks to wheels (et)</td>
<td>Well to wheels (cw)</td>
</tr>
<tr>
<td></td>
<td>MJ/kg</td>
<td>MJ/l</td>
</tr>
<tr>
<td>Petrol</td>
<td>43.2</td>
<td>32.2</td>
</tr>
<tr>
<td>Ethanol</td>
<td>26.8</td>
<td>21.3</td>
</tr>
<tr>
<td>Petrol E5</td>
<td>42.4</td>
<td>31.7</td>
</tr>
<tr>
<td>Petrol E10</td>
<td>41.5</td>
<td>31.1</td>
</tr>
<tr>
<td>Diesel</td>
<td>43.1</td>
<td>35.9</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>36.8</td>
<td>32.8</td>
</tr>
<tr>
<td>Diesel D5</td>
<td>42.8</td>
<td>35.7</td>
</tr>
<tr>
<td>Diesel D7</td>
<td>42.7</td>
<td>35.7</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>45.1</td>
<td>n/a</td>
</tr>
<tr>
<td>Liquefied petroleum gas</td>
<td>46.0</td>
<td>25.3</td>
</tr>
<tr>
<td>Jet kerosene</td>
<td>44.1</td>
<td>35.3</td>
</tr>
<tr>
<td>Heavy fuel oil</td>
<td>40.5</td>
<td>39.3</td>
</tr>
<tr>
<td>Marine diesel oil</td>
<td>43.0</td>
<td>38.7</td>
</tr>
<tr>
<td>Marine gas oil</td>
<td>43.0</td>
<td>38.3</td>
</tr>
</tbody>
</table>

For calculation of unit climate change costs, the handbook of external costs was used and cost estimated as 90 € per 1 tonne of CO2 equivalent. During the adaption of the methodology in the study, there were identified difficulties in sourcing values that are directly-measured from
the Kenya rail service, and thus standard/default values were applied. On the applicability of the developed method, the calculation really must be adapted to the objectives of the investigations and the possible way of selecting or determining the required inputs.

Figure 57. TIPI for environment aspect, GHG emission factor in € CO2e per passenger-km for diesel with biofuel proportion type of passenger train

Figure 58. TIPI for environment aspect, GHG emission factor in € CO2e per passenger-km for a diesel passenger train.
Chapter 3: Developed model testing, applications

Figure 59. TIPI for environment aspect, GHG emission factor in € CO2e per passenger-km for electric (renewable sourced energy) train

Figure 60. Proportions for electricity production in Kenya.

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%
Chapter 4: Integration of models into rail transport strategic management

4.1 ANALYSIS OF THE RESULTS FROM DEVELOPED MODELS

Demand accessibility forecast tool

The applied forecasting methodology includes four major cycles:

- concept development (adaption 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).

Transport inputs are generally 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.”

The selected and applied indicators for developed countries differ with those of developing countries since one has to tailor depending on social, economic, technical and technological levels of a country/region.

The demand for a functioning rail system increasing rapidly since the road system is over capacity limits and rather weak and the economy of the Nation is well growing.

The “s”-curve model approximates the market penetration, and technology adoption, also the speed at which a new technological solution supersedes the previous one.

Dummies identify the changes in the indicators caused by different events. For example, (i) introduction of new revolutionary new technologies, with considerably improved performance, (ii) improvements in regulations, (iii) step change in the infrastructure, (iv) other demographic, or cultural events. This thesis has identified the following relevant dummies:

- 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
o Nairobi Metro 2030 Strategy modernisation of the existing commuter rail network
o Rail passing through national park significantly promoting tourism.

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 more than on one or two important economic indicators, like GDP (see dating the NBER business cycles). 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.

There were studied statistical characteristics (as correlation data), 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.

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:
  o 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) - as a fixed investment is related to changes in vehicle fleets and diversification of activities,
  o 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,
  o 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.
Generally, the detected effects must be verified, and they need further investigation by use of more reliable and decomposed data and more sophisticated dating methodologies

**Energy-saving strategies tool**

*Train tram hybrid applicability*

More than 80% of 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 system thus the morphological matrix was applied to illustrate the features contributing to the train-tram hybrid being the ‘most suitable system solution’ for developing countries.

The trams are ideal for short journeys with frequent stops, and the cost of railway electrification means that only the heavily used routes can be electrified yet with a possibility of having train tram with mixed operations on heavy rail tracks would give the country maximum benefits utilising available resources.

The train tram model would also allow the system to enjoy the benefits of regenerative breaking

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

The specific energy consumption equation:

$$E_{spc} = \left\{ 0.0172 \times \frac{V_m^2}{p_d} \times \frac{M_e}{M} + 0.2778 \times \frac{r}{p} \times \frac{D'}{D} \right\} \frac{Wh}{t-km} \quad (23)$$

Improved $p$ - overall efficiency of train components result in a reduction in energy consumed.

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. This thesis has investigated the effects of load change, to demonstrate on how to acquire 3kV (high voltage testing) and how the circuit responds to breakdown. Also, the error for the feedback system tends to zero, making it stable. The routine check of an apparatus helps obtain statistical information about its health and defects are detected early, besides, after a major alteration such as rewinding of electrical machines it is recommended to carry out the test. This way, the efficiency of the electrical apparatuses is increased; thus, overall enhancing the performance of rail by reducing the unnecessary loss of energy.
Total impact analysis

Sustainability is a primary objective of developing future railway vehicles and transportation systems. This thesis recommends to use a 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):

The TOPI- total operation performance index 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 -total impact performance index deals with the externality. It is the index that might be used in impact assessment.

This thesis follows the developing total impact evaluation methodology and creates a unique excel table for its application. Excel software was considered due to its simplicity and availability towards an effort to create a user-friendly tool. Applicability of the methodology is demonstrated by analysis of safety and environment aspect rail transport. At first safety in terms of accidents is investigated for some selected countries in the European Area, then the environmental impact in terms of CO2e emission for Kenya.

These calculations must be adapted according to the objectives of investigations, there were classified ‘others’ accidents risks, this may include the effect of congestion on the accident risks and delay in travels because of the accidents or congestions initiated by accidents which are recommended to include in the accident's consequences. However, it was found that it wouldn’t be justifiable to compare TIPI for different countries because the cost conversion is not standardised and rather depends on the country’s economy. However, though Germany has a higher willingness to pay to avoid casualties their safety index in terms of rail accidents is visibly higher than other EU selected countries.

On the other hand, 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%. During the adaption of the methodology in the study, there were identified difficulties in sourcing values 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 was found that its also possible to add specific indicators/parameters column in the excel table. The results show that the developed methodology user-friendly can be applied for evaluating the total impacts of transport vehicles, transport companies, regional transport systems, and transport means. Further works will include calculations of other sub-groups of impact for a different mode of transport and realising forecasts results based on the calculated historical data.

4.2 DEVELOPING STRATEGIC MANAGEMENT SUPPORTED BY DEVELOPED MODELS

The effective functioning of the Kenyan rail system would play an exceptional role in creating the conditions for modernisation, the transition to an innovative path of development and sustainable growth of the nation and contribute to the creation of conditions for ensuring Kenya’s leadership in the regional economic system. Not only the prospects for further socio-economic development depend on the state and performance of rail transport but also the ability of a country to perform crucial functions such as ensuring the needs of citizens in transportation, creating conditions for equalising the social-economic development of the regions. Besides, the process of globalisation, change from traditional region economics relations pose the task of Kenya to rationally use the potential of its unique economic and geographical position.

To develop the tools necessary for supporting the decision in rail strategy management for Kenya, there were studied a pattern of past data of rail transport volume (passenger-km & ton-km) to deduce usability, the technical and technological backlog from the developed world in terms of railway equipment, the availability of resources, the decline of railway transport in SSA which requires immediate attention in updating the fixed assets of the railway transport, a possibility of bringing the performance and safety of transportation per the requirements of the population, economic level and the world standards based on the technological and technical development of railway transport.

The railway transport development can be affected significantly by dynamics of prices in the fuel industry, electric power industry, lagging dynamics of technological advancements as well as a decline in the planned volume of country’s investments. Regular monitoring and analysis of indicators, such as changes in GDP, dynamics of growth rates and population structure, changes in the structure and volume of transportation, changes in the structure rolling stock, changes in other modes of transport, depreciation of fixed assets of railway transport, the intensity of innovation and their level of use etc. help develop a response mechanism and mitigation.
4.3 APPLICABILITY OF THE MODEL SUPPORTED STRATEGIC MANAGEMENT PHILOSOPHY

Strategic management is related to the survival and growth of an organisation, from time standpoint is the continued existence in the future. Future challenges emerge in the turbulent environment and strategic management often struggles to keep up with unpredictable changes, but with support model/guides, it is well prepared for the ripples. In other words, in a complex, modern, dynamic, competitive environments, characterised by economic, social, cultural and technological changes, the proposed models deem essential.

Gathering and analysis of information and data relevant to this study have been analysed to understand the need, opportunities, direction and initiatives needed to help advance the rail transport system. Formulation of the models depending on future needs has been reviewed and defined as objectives of the study. The proposed models assist in evaluation and control focusing not only in present significant issues but paying a good deal of attention to future significant issues as well.

Strategic management goes beyond experience and mainly base their decision on theoretical forecasts to prevent serious strategy failures/errors. The models proposed in this thesis helps to develop scientific forecasts beyond experience. However, not all strategic management issues can be tested. For instance, if a historical event was to be replayed, would the successes or failures of the event be bound to be the same? There can be no definitive answer because history will not be replayed. Our models extrapolate from the experience of past into the future, mainly based on the assumption that history could be replayed in the future, analyses using theoretical/mathematical calculations and projects the possible turn out of events.
Chapter 5: Conclusions - theses

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


Bibliography


DOI: 10.1109/TEC.2004.837304.


Appendices

Appendix A

Kenya passenger rail demand forecast

clc
[num, txt] = xlsread('Kenya_revised.xlsx');

t = num(1,:); % Call years
g = num(2,:); % Population data
g1 = num(3,:); % Goods transported
g2 = num(4,:); % passenger carried
g3 = num(5,:); % Gdp per capita
g4 = num(6,:); % Secondary school enrollment
g5 = num(7,:); % Power consumption per capita
dt = 1;

subplot(2,4,1)
plot(t,g)
xlabel('Year')
ylabel('Population')
title('Population, Kenya')

subplot(2,4,2)
plot(t,g1)
xlabel('Year')
ylabel('Goods transported Million Tonn-km')
title('Goods Transported, Kenya')

subplot(2,4,3)
plot(t,g2)
xlabel('Year')
ylabel('Passenger carried Million passengers-km')
title('Passenger Carried, Kenya')

subplot(2,4,4)
plot(t,g3)
xlabel('Year')
ylabel('GDP per capita')
title('GDP, Kenya')

subplot(2,4,5)
plot(t,g4)
xlabel('Year')
ylabel('Secondary School enrollment (% gross)')
title('Education, Kenya')

subplot(2,4,6)
plot(t,g5)
xlabel('Year')
ylabel('Electric Power consumption (KWh per Capita)')
title('Electric Power consumption, Kenya')

% forecast drivers

T = 15; % forecast horizon
tf = t(end)+1:t(end)+T;

jj = 1;
for j=6:8
    n = j; % order
    model_g = ar(g',n);
gf(:,jj) = forecast(model_g, g', T);
jj = jj + 1;
end

subplot(2,4,1)
hold on
plot(tf,gf)
legend('data','ar6','ar7','ar8')

jj = 1;
for j=6:8
    n = j; % order
    model_g1 = ar(g1',n);
g1f(:,jj) = forecast(model_g1, g1', T);
jj = jj + 1;
end
subplot(2,4,2)
hold on
plot(tf,g1f)
legend('data','ar6','ar7','ar8')

jj = 1;
for j=6:8
    n = j; % order
    model_g2 = ar(g2',n);
    g2f(:,jj) = forecast(model_g2, g2', T);
    jj = jj + 1;
end

subplot(2,4,3)
hold on
plot(tf,g2f)
legend('data','ar6','ar7','ar8')

jj = 1;
for j=6:8
    n = j; % order
    model_g3 = ar(g3',n);
    g3f(:,jj) = forecast(model_g3, g3', T);
    jj = jj + 1;
end

subplot(2,4,4)
hold on
plot(tf,g3f)
legend('data','ar6','ar7','ar8')

jj = 1;
for j=6:8
    n = j; % order
    model_g4 = ar(g4',n);
    g4f(:,jj) = forecast(model_g4, g4', T);
    jj = jj + 1;
end

subplot(2,4,5)
hold on
plot(tf,g4f)
legend('data','ar6','ar7','ar8')

jj = 1;
for j=6:8
    n = j; % order
    model_g5 = ar(g5',n);
g5f(:,jj) = forecast(model_g5, g5', T);
jj = jj + 1;
end

subplot(2,4,6)
hold on
plot(tf,g5f)
legend('data','ar6','ar7','ar8')

%% ARX model

data = iddata(g2',[g',g3',g4'],1);
jj = 1;
for j = 1:2
    model_g2t = arx(data,[j,[j,j,j],[1,1,1]]);
    %gtf = forecast(model_gt,data,T,[g1f,g2f,g3f]);
g2tf = forecast(model_g2t,data,T,[gf(:,1),g3f(:,1),g4f(:,1)]);
g2arx(:,jj) = g2tf.OutputData;
jj = jj + 1;
end
subplot(2,4,7)
hold on
plot(t,g2,tf,g2arx)
xlabel('Year')
ylabel('passenger carried')
ylim([0 500])
title('ARX - GDP+EDU+POP')
legend('data','arx1','arx2')
data = iddata(g2',[g',g3',g5'],1);
jj = 1;
for j = 1:2
    model_g2t = arx(data,[j,[j,j,j],[1,1,1]]);
    %yxf = forecast(model_yx,data,T);
    g2xf = forecast(model_g2t,data,T,[gf(:,1),g3f(:,1),g5f(:,1)]);
    g2arx(:,jj) = g2xf.OutputData;
    jj = jj + 1;
end
subplot(2,4,8)
hold on
plot(t,g2,tf,g2arx)

global tsm N0
Nt1 =
[384,393,346.800000000000,302,158.700000000000,166
  200000000000,288,257,226,187.080000000000,148.160
  00000000,109.240000000000,94,88,85,92,104,126,137
  ,165,187.134939581635,225.978575157245,260.2845105
  92912,292.302476713983,333.760851477457,373.998896
  733927,415.952242345670,458.814346236952,495.58835
  9277307,527.557699880085,555.287290975958,577.1926
  70244282,594.376465145403,606.997390804485,614.603
  995695551];
t1 =
  ,2026,2027,2028,2029,2030];
% the points first
%plot(t1,Nt1,'bo');
%grid on;
hold on;
%1st approximation
k0 = [0.8 ,0.6];
tsm = 1996;
N0 = Nt1(1);
k1=lsqcurvefit(@Gompertc,k0, t1, Nt1);
%1st part graph(past data)
t=t1(1):1:t1(end);
Nt=Gompertzc(k1,t);
plot(t,Nt,'r')
hold off

xlabel('Year')
ylabel('passenger carried')
ylim([0 500])
title('ARX - GDP +POP +ELEC')
legend('data','arx1','arx2','gomp')

function Nt=Gompertzc(k,t)
global tsm N0
Nt=N0*exp(k(1).*(1-exp(-k(2).*(t-tsm))));
end
## Appendix B

### Total impact analysis excel table

<table>
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<th>Group of impact</th>
<th>Group of impact</th>
<th>Impact indicators</th>
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<th>Cost consequences</th>
<th>Total impact</th>
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<td>Environment</td>
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<td>Transport</td>
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<th>Impact indicators</th>
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