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Sustainable development models strategies analysis in the dynamic railway industry linking technological transformation

Análisis de estrategias de modelos de desarrollo sustentable en la industria dinámica ferroviaria vinculando la transformación tecnológica

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Abstract

Currently there is a global need to generate a sustainable development model that optimizes the functioning of the dynamic railway industry and that can be updated along with technological transformations. The objective of this research was to analyze the strategies of sustainable development models in the dynamic railway industry, linking technological transformation to ensure its long-term operation. On the other hand, railway systems that operate with well-structured sustainable development models have ample possibilities of long-term persistence, however, railway systems that lack this are destined to fail before the economy that can generate subsidies detonates. The methodology was carried out by a mixed analysis for it, it was relevant the application of quantitative and qualitative methods of parameters of sustainable development in train systems based on control variables such as economic, social, environmental, equity, areas. Socio-economic-environmental, stability, viability and ecological. The technical data obtained from different sources of scientific information were the basis for decision-making that contributed to the formulation of a sustainable development model in railway systems. The characterization and optimization of the model will be the subject of future work.

Railway systems, Sustainable development, Subsidies

Resumen

En la actualidad existe la necesidad mundial de generar modelos de estudio de desarrollo sustentable que optimice el funcionamiento de la industria dinámica ferroviaria y que pueda actualizarse a la par de transformaciones tecnológicas. El objetivo de esta investigación fue analizar las estrategias de modelos de desarrollo sustentable en la industria dinámica ferroviaria vinculando la transformación tecnológica para asegurar su operación a largo plazo. por otro lado, los sistemas ferroviarios que operan con modelos de desarrollo sustentable bien estructurados tienen amplias posibilidades de persistencia a largo plazo, sin embargo, los sistemas ferroviarios que carecen de este están destinados al fracaso antes de que detone la economía que puede generarle los subsidios. La metodología fue llevada a cabo por un análisis mixto para ello, fue relevante la aplicación de métodos cuantitativos y cualitativos de parámetros del desarrollo sustentable en sistemas de trenes en función de las variables de control como económica, social, medioambiente, equidad, ámbitos socioeconómico ambiental, estabilidad, viabilidad y ecológica. Los datos técnicos obtenidos de diferentes fuentes de información científica fueron la base para la toma de decisiones que contribuyen a la formulación de un modelo de desarrollo sustentable en sistemas ferroviarios. La caracterización y optimización del modelo será motivo de trabajos futuros.

Sistemas ferroviarios, Desarrollo sustentable, Subsidios

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Introduction

The world demand for transport is growing logarithmically in the transfer of passengers and cargo, due to social and economic progress, however, this will generate a demand for energy and greater atmospheric polluting emissions in the next century. The railway has the potential to reduce this growth in urban environments. High-speed rail is an alternative to short-distance air travel, and freight rail can complement other modes of transportation by providing efficient mobility (Global Railway Review, 2022).

Transport annually consumes around 50% of world oil production with around 25% of the planet's polluting emissions. Therefore, the implementation of a railway transport in its different energy modalities in trajectories typical of this transport reduces the time of transfers and pollutants, making it an efficient means of transport. Currently, railway systems transport around 10% of passengers and merchandise globally with an energy demand of around 2% of world oil production.

Currently, 800 million people in the world are mobilized by rail-electric transport, while a couple of decades ago there were around 320 million people. The railway sector is the system that has the greatest affinity for electrification due to its infrastructure conditions and that will hardly be matched by the automotive, aeronautical, and maritime sectors in the coming decades. Passenger rail systems present 90% greater electrification than freight systems.

The regions with the greatest activity for high-speed electric trains are Europe, Japan, and Russia, while Latin America depends on hybrid systems or fossil fuels in low-speed rail systems of less than 250 km/h on short, medium, and long distances.

Conventional railways account for about 90% of global passenger movements, first India with 39%, China 27%, Japan 11%, and the European Union 9% (Sustainability – UIC - International union of railways, 2023).

Currently there is a global need to generate sustainable development study models that optimize the functioning of the dynamic railway industry and that can be updated along with technological transformations.

The objective of this research was to analyze the strategies of sustainable development models in the dynamic railway industry, linking technological transformation to ensure its long-term operation.

On the other hand, the railway systems that operate with well-structured sustainable development models have ample possibilities of long-term persistence, however, the railway systems that lack this. They are destined to fail before the economy that the subsidies can generate for them explodes.

Sustainable development

Sustainable development is an action that nations use to promote a global economic development model for environmental conservation with social equity.

This satisfies the needs of the present without compromising the ability of future generations to satisfy their own needs by putting it as a "political manifesto" citizens, civil organizations, companies, and governments to promote actions, ethical principles and new institutions oriented towards a common objective: sustainability.

The holistic vision of sustainable development has been challenged by a broader, complex vision where the quantitative is subsumed in the qualitative – which articulates care for the environment, as well as the integrity of ecosystems, solidarity-based social relations oriented towards equity and the institutional environments of politics for the exercise of governance. The priorities of sustainable development and efficient implementation of integrated policy decisions require institutional changes at different levels and involve all private and government sectors, see figure 1.

The 2030 Agenda comprises 17 Sustainable Development Goals structured into 169 goals, the description of which has as its central axis people, the planet, prosperity, collective participation, and peace with the purpose of ending poverty, fighting against inequality, injustice, and guarantee the protection of the environment and its natural resources.

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This is universal and transformative, an ambitious action plan to redirect the world towards a sustainable future, it takes up the Millennium Development Goals and is an opportunity to develop new procedures and intensify efforts that manage to influence the fulfillment of the goals and aspirations set forth by the international community (Cepal, 2019, SUSTAINABLE Development, 2018 and Zawadzki et al., 2022).

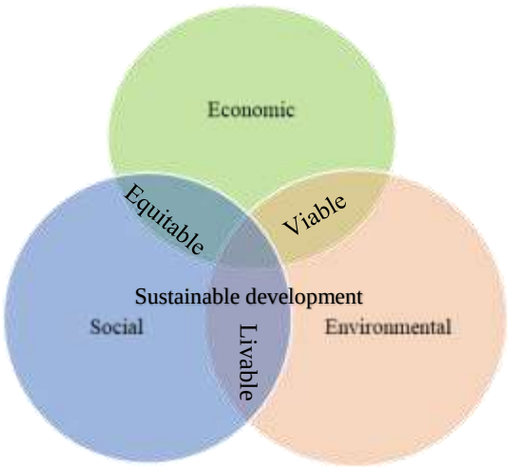

Figure 1 Venn diagram, sustainable development, Group of Tribology and Transportation Faculty of Engineering BUAP; 2023

Railway systems; A solution to urban mobility?

The growth in the railway networks for 2050 was estimated with an increase of 2.7 times with respect to the year 2023. Highlighting India and Southeast Asia which will have an increase of seven times, China three times, Japan 0.25 times and 0.45 times the European Union. Railway movements mobilize around 10% of the world population and two thirds of freight transport is carried out on electrified railways, it is expected to reach an electricity consumption of around 700 TWh.

The incorporation of a railway system to a densely populated area will generate capital gains in the value of real estate and land, capitalization of commercial areas, improve mobility and public policies will be implemented to ensure that these transformations provide subsidies to the railway industry. The implementation of regulations that regulate the collection of taxes for train subsidies could be implemented as charges to alternative means of transportation based on the pollutants they generate, charging for road congestion, and road pricing.

Air pollution and mitigating climate change are global concerns. A previous analysis shows that rail systems are 12 times more efficient in energy consumption and pollutant emissions compared to road and air travel in terms of "final energy per passenger transported" and eight times more efficient than trucks per "ton of cargo transported". The efficiencies of the railway system are due to the reduction of the coefficients of friction in the rolling area in the metal-metal contact, which minimizes the torque required by the motor source, which decreases the energy consumption when dragging cargo with positive impacts. Economically and environmentally (Transforming our world: the 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs, s. f.).

The railway transport modeling for the evaluation of sustainable performance through sustainability indices such as; environmental, energy consumption (green mode of transport), social, greenhouse gas emissions, noise pollution, poor management performance, performance evaluation, identification of indicators that hinder sustainable performance, policies, axes of government plans and programs, driving standards of sustainability, reduction of accidents, climate change, competitive logistics, inclusion of intermodal road-rail transport means, analytical hierarchy process findings, logic methods, specialized methodologies (fuzzy logic, fuzzy spherical environment, neural networks, data mining, quality, decision-making based on public policy priorities freight transport imposition of how to promote consumer preference expansion of transport with global trends), reasonable access to cargo facilities equitable ecological manner (supply chain) (Railway-News, 2023).

Sustainability must be included in the objectives of a transport company, however, in practice and in decision-making, sustainability is not seen as the main concern of transport companies, governance and policy development incentives and sanctions. This is a concern because non-quantifiable variables depend on people's point of view but affect decision making in higher percentages than those made through quantifiable analysis.

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Dynamic sustainable development models with control variables

Proximity to railways, highways and feeder roads have an impact on the expansion of cultivated land, grassland and building land, protected areas, respectively, Future urban expansion is inevitable as predicted by global population growth models with influence on settlements in strategic areas of the planet. Large cities are the result of demographic growth in specific geographical areas with large concentrations, however, the expansion of these large cities creates scenarios of radial increase.

On the other hand, models of large cities have been carried out in some countries such as China, leading to the creation of model cities away from urban sprawl to disperse population concentrations, but the result is null. These model cities represent large initial investments, maintenance, mobility infrastructure, subsidies and incentives for people who wish to inhabit them. The result obtained for these model cities is a resounding failure and they represent ghost cities with a large infrastructure wasted until the radius of the urban sprawl absorbs them. (Ciulli & Kolk, 2023)

The modeling of urban expansion projects can serve as a reference for ecological environmental protection planning and sustainable development of land resources. These big changes in land use are bound to bring a series of ecological problems, such as climate change. Urban ecosystems have been seriously damaged, to analyze the dynamics in a scientific and rational way, it will be of great importance to optimize decision-making and execution of urban expansion projects that can largely ensure their sustainability. Model-based projects with a scientifically sound approach with iterations in optimizing possible solutions before execution greatly ensure the sustainability of the project.

However, when a project is executed without a strategic planning with scientific feasibility bases, it is destined to fail and in the early stages of the project it will face great limitations and complications with minimal possibilities of reaching project maturity and much less long-term sustainability.

The interrelation between the landscape and human activities help to analyze the relationship between these in an ecological environment.

In decision-making in the development of land use through geographic simulation models that consider; the spatial and temporal dynamics of land use, under the influence of natural and human activities subject to transitions of multiple factors that dynamically and iteratively evaluate improvements based on the model, identifying strategies for the analysis of patterns typical of the geographical region and conditioning factors of the system to simulate. Dynamic sustainable development models with control variables based on the growth of land use to avoid ecological impact as far as possible use more and more specialized methodologies carried out by experts in different disciplines who provide knowledge for the identification of variables of system control.

The methodologies used for modeling are computational model iteration techniques, information technologies, data mining, regional ecological assessments receptor risk assessment, spatial and temporal regional assessment, heterogeneity scale effects, quantitative and qualitative assessment, ecological risk in the fragmentation and diversity of the complex, analysis of the relationship between the landscape patterns (Guo et al., 2022).

Ecological spatial pattern in upward spiral problems in sustainable development

Rapid urbanization has vastly changed urban ecological spaces and the function of regional habitats, threatening regional ecological security and landscape sustainability expanding habitat quality is important for ecological security.

Integrated land use, natural, social and economic factors to monitor and assess the impact of urban sprawl on habitat quality urban sprawl and ecological soil have become more fragmented urban sprawl has changed from edge to edge sprawl peripheral type; The rate of urban expansion increased exponentially in ecological corridors ecological nodes that form an ecological spatial pattern of building patterns of ecological security (Xuto et al., 2022).

Urbanization is an essential driver that generates challenges such as global climate change and sustainable development, directly or indirectly affecting the change in urban landscape patterns, an expansion that has occupied a large number of agricultural and ecological spaces.

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Resulting in more than 80% of the loss of natural habitat of local areas generating unbalanced and undeveloped urban ecological environmental areas driving global climate change, irrational human exploitation, ecologically based poverty, weak environmental capacity, water scarcity, and waste control by infrastructure non-existent in non-urbanized areas but that are triggered by the stimulation of distances being brought closer by the railway system, propitiating an ascending spiral of problems that relate the area to sustainable development.

In order to generate a project for a railway system with compliance with sustainable development, it must cover a very complete project with a 100-year growth and that the train service supply area is based on demographic growth, which, after all, will be the future customers and users of the train, so crossing a reserve with a railway system represents a project with minimal expansion growth if its purpose is its conservation, which is why this type of project puts ecological reserves at risk. The development of railway systems without a well-founded feasibility study that invade agricultural lands and areas of endemic flora in the region generate an impact of land use change with irreparable ecological damage.

The urban core of a region generates expansive growth according to demographic growth and, although exponentially and sometimes uncontrollably, they present a typified spatial pattern of growth; however, rapid urbanization due to the creation of railway systems in demographic areas that do not demand its utility due to its limited growth, it will generate an altered spatial pattern with invasion of regional habitats and represents a serious threat to habitats and biodiversity.

Research on the ecological impacts of urban expansion, according to research methods, can be classified into three categories: first, ecological quality assessment (documentation of biomes, flora, fauna, grassland, arable land, water areas, forest land, unused land, construction land, city limit, groundwater areas, underground rivers, lagoons, mangroves, archaeological zones, studies of events in different paleontological eras of events in the region, among others), second, systems evaluation (environmental quality index, ecological, demographic expansion) and the ecological index of remote sensing.

Third, the quantitative and qualitative analysis based on the ecological model (assessment models, including Integrated Ecosystem Valuation, services and compensation model, artificial model. The intelligence model for ecosystem services, social values model for ecosystem services, minimum cumulative resistance model among others, since the purpose of the ecological impact study must fully evaluate ecological safety, environmental impact analysis and prediction.

Regional habitat quality studies are limited by available land, so data collection in historical periods and in future scenarios. The scope of this study explores the current situation and spatiotemporal variations of habitat quality in urban areas, agglomerations, or individual cities.

The evaluation of the ecological impacts of urban expansion from the perspective of a pattern of ecological security of land use change. The global ecological and environmental problems that threaten the sustainable development of human society place as a priority the development of plans and programs to safeguard ecological security. This consists of three parts, first identification of the area of origin, second determination of resistance surfaces and third construction of ecological corridors.

This evaluation model develops direct identification and a comprehensive evaluation index system, core areas of nature reserves and scenic spots, indicator ecological sources, ecological sensitivity, landscape connectivity, habitat importance, morphological spatial pattern analysis method, model to overcome the deficiencies of the model, selection of areas of origin graph, theoretical method, theory of circuits to evaluate the structure of the ecological security pattern, areas of ecological origin that are most suitable for the status of species according to the headquarters necessary for generate current habitat quality, distribution map, natural, social and human influencing factors, identification and planning of ecological patterns the model main purposes explore spatio-temporal characteristics assess ecological security study area covering seven types of land use Land:

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Cropland, Forest, Grassland, Shrubland, Wetland, Water, Impervious Surface, and Bare Land Land-use data to explore spatiotemporal characteristics of land-use cover/change in natural habitat loss (Wei et al., 2022).

Ecological security pattern models and zoning of complex dynamic systems

Building models of ecological security and zoning patterns in complex dynamic systems greatly ensure the reduction of ecological risks in developments associated with rail transport infrastructure. Modeling diminishes major threats to biodiversity and ecosystem services, mitigating threats along rail infrastructure, by pre-assessing landscape ecological risk, regional resilience, ecological quality index, segmentation, and penetration of high-risk areas. risk and low-risk areas, highway expansion, identification and evaluation of risk areas, development of industrial parks, risks in urban areas, ecological corridors, connection with ecological sources, among others.

Mixed methods to integrate ecological risk assessment, promotion of infrastructure-driven ecological conservation planning and industrial parks. Influenced by the rapid development driven by transport infrastructure, evaluation of the magnitude of risk, infrastructure trends and industrial parks generating high risk such as; geological hazards, erosion by rain, expansion of human activities, amplification of risks under demands for anthropic intervention, design of corridors for the survival and migration of species with specific solutions aimed at each existing species in the area, design of monitoring the behavior of species migrations with impacts on genetic evolution and zoning optimization.

On a holistic scale, it was driven by type of land use and vegetation cover, while, on a local scale, low-risk areas were primarily shaped by landscape resilience ecological sources corridors, basically connecting most areas with good vegetation cover and important ecological functions this provides management tools adaptable to the synergies between development and mitigation of landscape risks (Bai & Weng, 2023).

Modeling of autonomous service agents; fixed routing or on demand

The potential of autonomous vehicle technology for a light rail station uses first and last mile services as mobility models. Event and agent simulation model Based on a matching algorithm, incoming passenger requests are prioritized and assigned to vehicles with capacity constraints. Urban sprawl has an impact on system performance, services become relatively better to meet urban sprawl, while fixed routing remains superior in most key performance indicators.

Urbanization and development have led to larger and denser cities, caused congestion, synchronously with the development in autonomous transportation technologies. The deployment of efficient feeder strategies will have an impact on the design of cities, quality transport services, equity perspective. First and Last Mile Feeder Services is a light rail model that accounts for demand in space-time, route and bus stop design, integration of capacity constraints, and routing algorithms in an agent-based simulation model. Queuing systems with data analysis.

The intricate logic of the model is described in a series of event-based graphs and pseudocode that describe event transitions demonstrating that fixed routing performs better than demand response scenarios when evaluated in a cost-effectiveness framework. The benefit, fixed routing is more robust and can handle variations, what makes it much more consistent is that the optimal route design is circular and synchronizes with the light rail frequency (Rich et al., 2023).

Plans and programs for sustainable development in train systems

The impact of urban light rail systems reduces congestion, travel time and pollution. An analysis of differences to a sample of cities that did not have rail systems in the initial year. The evidence determines that an increase in the supply of rail transport leads to less congestion, less travel time and pollution. The European Commission revealed that congestion due to road transport generates polluting emissions and are the main cause of deaths per year in the world (more than AIDS, malaria and flu combined).

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Light rails offer great advantages in urban mobility such as, they operate on steep slopes, tight curves, travel speed, reliability and can carry up to three times more passenger capacity than a bus, however, light rails are more expensive than regular buses. One of the variants worth explaining is that light rail transport prices are much lower, which benefits social equity, but this is because the provision of subsidies makes prices competitive with other means of transport functioning as a means of regulating the economy with an impact on different sectors.

However, the cost of km traveled per unit is much higher, so how can you have competitive prices? This is because the subsidies contribute to lower the final price of mobility in the light rail system, and it is provided by the government for the different income such as taxes and rental of spaces of the railway infrastructure. (Liu et al., 2023)

The trains in their different classifications are intended for large cities with large demographics so that they generate an impact in reducing travel time, traffic and pollution that increase over time, previous studies indicate that cities with a new rail system have a 7 % less congestion, 1% less travel time and 3% less pollution than cities without a rail system (Fageda, 2021).

Train projects under these conditions may represent a partial solution to these problems, but their impact will be appreciated over the years with population growth, which is why sustainable development models are even planned for long terms (100 years).

It is worth mentioning that a railway system is a company which, due to its complexity in terms of factors such as initial investment, maintenance, modernization, and quality of the system, according to previous studies from different countries, does not represent a competitive company in prices to the user or a company that generates great economic profits.

The objective of a railway system is to contribute to the reduction of travel time, traffic and pollution, but it should not be forgotten that due to the complexity of the system and the variations in the subsidies of the different levels of government.

Over the years it can become inoperative due to the high costs that it requires and in many cases the railway infrastructure is abandoned due to the high operating costs and the infrastructure is plundered by the people of the region, becoming a source of contamination to the ecosystem and a project that to operate again will require large investments to recover the lost infrastructure and enable the system to make it operational. Another factor that must be considered is that the useful life of a train, although it depends on its extension due to due maintenance, like all machines, has a useful life limit and that the plans and programs of railway projects in the long term (100 years) take into consideration that the system will have to be replaced at least three times in the periods of technology renewal, in case of not doing so, serious accidents will occur that will take the lives of the users.

Methodology

This research has a mixed approach, applying both quantitative and qualitative technologies, using systematic processes, as well as recorded and estimated data. The aims of this research was to analyze the strategies of sustainable development models in the dynamic railway industry, linking technological transformation to ensure its long-term operation. The methodology was carried out by a mixed analysis, for this, it was relevant the application of quantitative and qualitative methods of parameters of sustainable development in train systems based on control variables such as economic, social, environmental, equity, socio-economic-environmental spheres, stability, viability, and ecology.

The technical data obtained from different sources of scientific information were the basis for decision making that contribute to the formulation of a model of sustainable development in railway systems. Sustainable development models proposed by different researchers and experts in the area of railway systems, belonging to different countries and international organizations that have exhaustive monitoring in the railway area, have developed iterative models of railway technological development with different scientific techniques, (they were documented through different means such as; technical reports from international organizations, case studies reported in international papers, cases documented by formal media, etc.).

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Conclusions

At present there is no complete model that can lay the foundations according to the regulation of variables of a model of sustainable development of railway systems, because this would be a complex model that covers several disciplines and decision-making with respect to the projects of railway systems in their different stages are regulated by qualitative analysis above the quantitative ones, depending on the appreciation and convenience of those responsible for the project in their different execution positions, which follow trends that suit their interests, making them fall more Number of errors that will affect the railway system in its different stages until its renewal or failure.

The models of railway systems are considered by discipline as isolated case studies and specialized computational techniques can be applied for their iteration, however, there are non-programmable criteria such as qualitative criteria that do not allow generating a model for that case study with accurate decisions since it depends on the person(s) making the decision. Most of the companies and governments, faced with this situation, overlook the majority of case studies that must support a railway project by venturing into construction and then adapting studies with decision-making based on their results in work and environment.

However the train does not forgive and the race in favor of subsidies, depreciation, maintenance, modernization of a project of this nature in conjunction with errors during the construction stages of the project will make the failure approach before the renewal of the system in one stage early with no possibility of reaching that triggered the sustainable development of the project.

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