Railway Engineering: Timetable Planning and Control, Artificial Intelligence and Externalities

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Chapter 17
Railway Engineering:
Timetable Planning and Control, Artificial Intelligence and Externalities

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ABSTRACT

This chapter is a case study of the dissemination of railway engineering research in Latin America developed by a railway engineering research group. The leader of the group is a female researcher. The authors aim to inspire to other women researchers in Latin American and Caribbean (LAC) countries who are trying to develop research in IT areas, many times facing serious difficulties, incomprehension, and great challenges. This chapter is divided in set sections like introduction, background, development of railway engineering research. This third section is divided into subsections like timetable planning and trains control, characterization of Panama metro line 1, dwelling times, fuzzy logic, artificial intelligence, social-economics railway externalities, and environmental railway externalities. The fourth section presents the results of the relationship between research activity and teaching of railway engineering obtained in this case study. Finally, the authors present a brief vision about future and emerging regional trends about railway engineering projects.

INTRODUCTION

This chapter presents a case study on the efforts of a Latin American railway engineering research group, including research activities, railway engineering courses, and other complementary activities. Railway engineering is a multidisciplinary engineering discipline focused on the design, construction, operation, inspection, and evaluation of rail transportation systems like metro, railroad, commuter train,

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tramway, light rail, and monorail. This high-tech discipline includes a range of engineering disciplines like civil engineering, computer engineering, electrical engineering, mechanical engineering, industrial engineering, telecommunications engineering, and railway externalities.

In the Latin America and Caribbean (LAC) context of urban transport systems, avenues of research are emerging that exploit nontraditional sources of data like big data and satellite information (Yañez-Pagans et al., 2019). Several studies explore ways to improve the operational efficiency of systems (Yañez-Pagans et al., 2019). Those seeking to promote behavioral changes in transport use can generate learning that is useful to both public and private actors involved. The science of artificial intelligence (AI) can develop rule-based expert systems, evolutionary optimization techniques, neural networks, and fuzzy logic related to solutions in railway transportation systems.

In general, transportation problems in the LAC are common. Fay et al. (2017) indicated that the LAC region has limited integration among transport modes, especially rail and road. For the rail infrastructure, Fay et al. (2017) indicated that density is less than 5 kilometers per thousand square kilometers for countries with a rail network as compared to 16 kilometers per thousand square kilometers for countries in the Organisation for Economic Co-operation and Development (OECD). In freight cargo, Mowatt (Mowatt & Cerra, 2017) found that the most mentioned constraint to export growth was infrastructure weaknesses and transportation costs. In the LAC, constraints were due to geography, including lack of adequate roads and railways, inefficiencies at ports and airports, and high costs when getting goods to market. To improve transport systems in Latin America, design systems must give priority to intermodality when transporting passengers and freight, which will make guided transport systems (metro and rail networks) the backbone of sustainable transport (Clemente, 2013).

The OECD, World Trade Organization (WTO), and the Inter-American Development Bank (IDB) (OECD et al., 2010) presented a snapshot of aid for trade on the ground about the LAC case stories. The publication indicated that projects to develop regional maritime transport and railroad networks were underway (OECD et al., 2010). For this reason, the IDB provided grant financing for feasibility studies and technical assistance in the region.

BACKGROUND

Railway engineering is considered a high technology development field with various research lines in prestigious universities, railroad research centers, and professional railway engineering associations. AI, a branch of computer sciences engineering performs tasks like visual perception, speech recognition, decision making, and translation between languages. This allows a computer program to think and learn like intelligent agents. Rail mobility, in coordination with the application of AI, can solve urban massive transit problems. There is extensive scientific literature regarding multiple applications of AI techniques in railway transportation systems. Table 1 presents these examples.

Table 1 shows a set of fuzzy logic applications in the railway transportation systems. Calic, Selmic, Macura, and Nikolic (Calic et al., 2019), Khosravi et al. (2017), Kaleybar and Farshad (2016), and Karakose et al. (2015) presented a scientific publication on topics like energy consumption prediction, railway traction, and pantograph-catenary systems. Calic et al. (2019) provided the Wang-Mendel method, combining numerical and linguistic information into a common framework (a fuzzy rule as a tool for energy consumption prediction). Khosravi et al. (2017) presented a fuzzy logic-based vector control of permanent magnet synchronous motor using stacked matrix converter for railway traction applications.

Table 1. Fuzzy logic application in railway engineering

Authors	Year	1	2	3	4	5	6	7	Institution, University, or Center
Calic et al.	2019	x							University of Belgrade (Serbia)
Milosavljević et al.	2018		x						School of Railway Applied Studies (Serbia)
De Aguiar, Amaral, Vellasco, & Ribeiro	2018		x					x	Federal University of Juiz de For a (Brazil), Pontifical Catholic University of Rio de Janeiro (Brazil)
Rozova, Sustr, Soušek, & Sohajek	2018		x	x					University of Pardubice (Czechia)
Dindar, Kaewunruen, & An	2018		x	x					University of Birmingham (UK)
Metin, Ulu, Paksoy, & Yücel	2018				x				Yildiz Technical University (Turkey)
Sasidharan, Burrow, Ghatoaora, & Torbaghan	2017			x		x			University of Birmingham (UK)
Zhang	2017		x				x		National Research Center of Railway Safety Assessment Beijing Jiaotong University (China)
De Aguiar, De Nogueira, Vellasco, & Ribeiro	2017		x					x	Federal University of Juiz de For a (Brazil), Pontifical Catholic University of Rio de Janeiro (Brazil)
Jamshidi, Núñez, Dollevoet, & Li	2017			x		x			Delft Univ. of Technology (The Netherlands)
Khosravi, Fazel, & Abdollahi	2017	x							Iran University of Science and Technology (Iran)
An, Qin, Jia, & Chen	2016			x					University of Birmingham (UK), Beijing Jiaotong University (China)
Menéndez, Martínez, Sanz, & Benitez	2016			x					Vías y Construcciones (Spain), Fundacion Cartif (Spain), Universidad de Granada (Spain)
Leonardi	2016			x					University of Reggio Calabria (Italy)
Kaleybar & Farshad	2016	x							Iran University of Science and Technology (Iran)
Karakose et al.	2015	x							Firat University (Turkey)
Pattanaik & Yadav	2015		x						Birla Institute of Technology (India)
Pamučar, Atanasković, & Milicic	2015		x						University of Defence (Serbia), University of Novi Sad (Serbia)

(1): Energy consumption prediction, railway traction, pantograph-catenary systems, (2): Safety and security railway engineering, train control system, level crossing system, (3): Risk, management, planning, mitigation decisions, infrastructure, maintenance decisions, (4): Vibrations estimation, (5): Simulation, Montecarlo technique, prediction, (6): Big data,
(7): Adaptive filter theory

Kaleybar and Farshad (Kaleybar & Farshad, 2016) presented a control strategy of railway power quality compensator for alternating current (AC) traction power supply systems using a recessive self-tuning proportional-integral (PI) controller based on fuzzy logic adopted in the current control system. Karakose et al. (Karakose et al., 2015) presented an arc detection method based on fuzzy logic using S-transform for pantograph-catenary systems.

An et al. (2016), Menéndez et al. (2016), and Leonardi (2016) developed their work in relative topics like risk, management, planning, mitigation decisions, rail infrastructure, and maintenance decisions. For example, An et al. (An et al., 2016) presented a modified fuzzy analytical hierarchy process (FAHP) approach that employs the fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis in the railway risk decision making process. Menéndez et al. (2016) presented a development of a smart framework based on fuzzy and computational intelligence techniques to support infrastructure maintenance decisions in railway corridors. Leonardi (Leonardi, 2016) outlined an evaluation framework that integrates fuzzy logic with multicriteria decision making in the context of infrastructure railway planning.

Milosavljević, Jeremić, and Vujović (2018), Pattanaik and Yadav (Pattanaik & Yadav, 2015), and Pamučar et al. (Pamučar et al., 2015) presented a scientific publication on aspects like safety and security railway engineering, train control system, and level crossing system. Milosavljević, Jeremić, and Vujović (Milosavljevic et al., 2019) developed a fuzzy logic application for train braking distance determination. Pattanaik and Yadav (Pattanaik & Yadav, 2015) presented a decision support model for an automated railway level crossing system using fuzzy logic control (FLC). The FLC model recognizes railway events as the arrival and departure of trains. The generated output action signals include the warning siren and control actions for the opening and closing of gates. Pamučar et al. (2015) worked with the modeling of a fuzzy logic-based approach that offers adequate support to management when prioritizing railway-level crossings without barriers with automatic signaling and/or interlocking systems.

Rozova et al. (2018) presented fuzzy prediction diagnostic as a crisis management solution in the railway transport regarding the security system of the Czech Republic. Dindar et al. (Dindar et al., 2018) reviewed adequate risk analysis techniques for railway turnout systems, mentioning the fuzzy logic technique and other analysis tools in uncertain conditions.

Metin et al. (Metin et al., 2018) noted that, to mitigate bridge vibrations, a semiactive magnetorheological (MR) damper with FLC is positioned at the ends of the bridge. Sasidharan et al. (Sasidharan et al., 2017) reviewed risk management applications for the railway industry. Regarding the integration of Monte Carlo with fuzzy reasoning, Sasidharan et al. (2017) found it could be especially pertinent to the railway industry as it would enable uncertainties associated with data and the credibility of expert judgement to gain a better understanding of risks and impacts of risk mitigation decisions. Zhang (Zhang, 2017) presented an analysis method based on the fuzzy RDF model and uncertain reasoning for high-speed train control system big data. De Aguiar et al. (De Aguiar et al., 2018) introduced the set-concept, which is derived from the adaptive filter theory. This concept is used with the training procedure of type-1 and singleton/nonsingleton fuzzy logic systems to reduce computational complexity and increase convergence speed. It also presents different criteria for its use with set-membership. Jamshidi et al. (Jamshidi et al., 2017) proposed a methodology based on a set of fuzzy key performance indicators in combination with a fuzzy Takagi-Sugeno interval model to predict squat evolution for different scenarios over a time horizon in railway infrastructures.

DEVELOPMENT OF RAILWAY ENGINEERING RESEARCH IN PANAMA

A Brief History of Railway Transportation Systems in Panama

The Panama Metro Line 1 is the first metro system in Central America. However, rail technologies are not new in the Isthmus of Panama. For example, the Panama Interoceanic Railroad, inaugurated in 1855, was the first transcontinental or trans-isthmian railroad (CPRR.org, 1988; Lienhard, 1988; Mahler, 2006; The Panama Railroad, 2008)The Chiriquí Railroad, whose construction began on April 23, 1914, was inaugurated April 22, 1916. Its development took place during the administration of President Dr. Belisario Porras. The Chiriquí Railroad's extension reached 81 kilometers (Berrío-Lemm, 2010; BPP, 2008; Castro-Stanziola, 2006; Panamá Vieja Escuela, 2014; Redacción de TVN noticias, 2017; Serracin, 2014). The project was the idea of President Pablo Arosemena in 1911 to connect Panama City with David City. It originally included a branch to the province of Los Santos. However, it was not carried out due to its excessive budget. President Porras, through Law No. 20 of February 19, 1913 (Gobierno de Panamá, 1913), authorized the feasibility studies of a provincial railway under the contract of the American company, R. W. Hubbard. In 1928, under the presidency of Rodolfo Chiari, the La Concepción railway track was extended to the town of Puerto Armuelles. A railway station was later built. The Chiriquí Land Company, a subsidiary of the United Fruit Company, obtained permission to build more branches to transport its banana crops (Wikipedia, 2020). Subsequently, a branch was built to the town of Boquete in the Chiriquí mountains. The Chiriquí Railroad ceased operation in the mid-1980s, mainly due to its high operating and maintenance costs and the existence of land routes that connected populations in a more efficient manner.

Prior to the construction and commissioning of the Panama metro network (Atencio, 2016; CEPAL, 2013; Metro de Panama(2017), 2017; Metro de Panama(2018), 2018; Metro de Panamá(2018), 2018; Metro de Panama & Consorcio línea 2, 2015; Republica de Panama & Consorcio linea 1, 2010), Panama City had an urban rail system, the urban tram, to transport passengers (Alonso, 2003; Bermúdez, 1996; Celerier, 2013; Morrison, 2003, 2008; Upegui, 2009; Vergara, 2015).This tram system operated until Saturday, April 31, 1941 at 6:00 p.m. More than 70 years later, the Panama metro began operations. The first metro line was inaugurated on April 5, 2014 (Panama Metro, 2019); the second metro line of Panama City was inaugurated on April 25, 2019 (González-Jiménez, 2019)(Rivera, 2019).

The Panama Metro Line 1 is 16 km. This metropolitan subway connects the north (at the San Isidro station) to the south (to the Albrook station). This final station connects with the National Bus Terminal of Transport's Albrook Bus Terminal, which serves the entire country and the city. In addition, this station is close to the local airport, Marcos A. Gelabert International Airport, and the Panama Canal Railroad (Berbey-Álvarez et al., 2019) (see Figure 1).

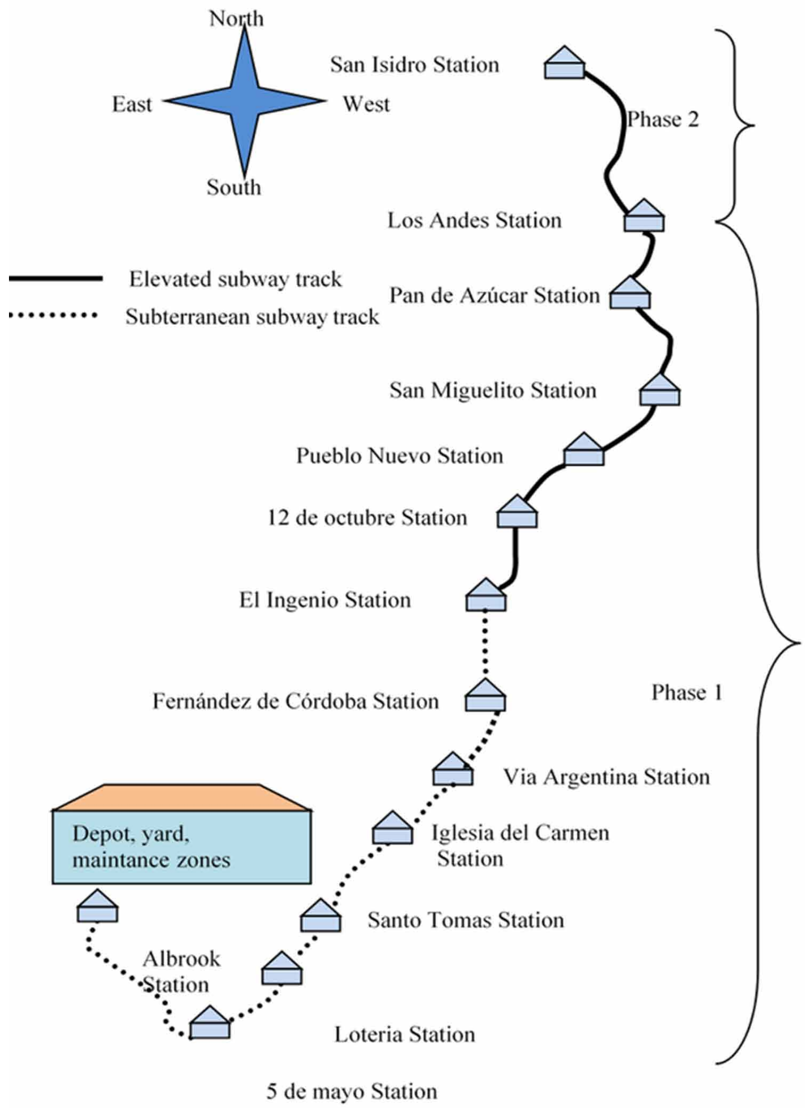
The first line of the Panama Metro has both elevated and subterranean tracks operated with a catenary-guided transport system (Berbey et al., 2014). The Albrook zone contains a storage facility and maintenance facility for rolling stock (a surface of 10 hectares). The operations control center (OCC) is also located in the Albrook facility zone. Rolling stock float trains have several three and five electric unit coaches, with a maximum capacity of 800 and 1,000 passengers per train, respectively (Metro de Panamá(2018), 2018). The dwelling time ranges from 25 to 30 seconds.

Timetable Planning and Train Controls

The control train systems' engineering applications monitor and control the trains' movements and protection systems. A regular interval timetable is characterized by train services in a fixed time pattern (Demitz et al., 2010). According to Hansen (Hansen, 2010), the timetable quality is governed by precise running time, realistic recovery times, optimal headway, and buffer times. Headway is the time distance between two consecutives vehicles in a transit system (Campion, G., Van Breusegem, V., Pinson, P. y Bastin, 1985) Rice, 1974; Sasama & Ohkawa, 1983; (VanBreusegem et al., 1991).In the case of Panama Metro Line 1, the headway is 3 minutes with 20 seconds between 6:00 a.m. and 8:00 a.m. (i.e., 18 trains/hour). It is 4 minutes with 30 seconds(i.e., 14 trains/hour) in off-peak hours (Metro de Panamá, 2020b).

In this line of ideas, Berbey-Alvarez, San Segundo, and de Dios Sanz Bobi (Berbey et al., 2008), Berbey, Caballero, Galán, and Sanz-Bobi (2009), and Berbey et al. (2014) proposed a Lyapunov-based index for designing a real-time rescheduling algorithm for metro lines. A modified real-time discrete

Figure 1. Scheme of Panama Metro Line 1 (Phase 1 and Phase 2) (Berbey-Alvarez, 2013)



space state model was proposed regarding the saturation effects in the metro line. The direct method of Lyapunov was applied to analyze the stability of the metro line system. As a result of this analysis, a stability index and establishment of three stability zones were proposed to indicate the current state of the system. The proposed algorithm allowed for a real-time rescheduling of the timetable for the trains under medium delay.

According to Google Scholar and ResearchGate Web platforms, research by Berbey-Alvarez et al. (2008, 2009, 2014) was cited by other authors (Kampczyk, Dybel, & Dybel, 2020; Khosrosereshki & Moaveni, 2019; Lai & Ip, 2017; Lai, Chen, Yan, & Li, 2018; (Moaveni & Karimi, 2017). This summary is discussed in Table 2.

Table 2. Summary of cited works

Authors	Year	1	2	3	4	Institution, University, or Center
Lai et al.	2018	x				National Taiwan University (Taiwan)
Moaveni & Karimi	2017		x			K. N. Toosi University of Technology (Iran)
Lai et al.	2017	x				National Taiwan University (Taiwan)
Khosrosereshki & Moaveni	2019			x		Iran University of Science and Technology (Iran) K. N. Toosi University of Technology (Iran)
Kampczyk et al.	2020				x	AGH University of Science and Technology (Poland)
(1): Simulation, (2): Predictive control, (3): Rail traffic regulation, (4): Welded rail						

Lai et al. (Y.-C. (Rex) Lai et al., 2018) presented a simulation-based method of capacity utilization evaluation to account for uncertainty in recovery time. Moaveni and Karimi (2017) developed a study about subway traffic regulation using model-based predictive control by considering the passengers' dynamic effect. Lai et al. (Y.-C. Lai & Ip, 2017) presented an integrated framework for assessing service efficiency and stability of rail transit systems. Khosrosereshki and Moaveni (2019) published a paper on metro traffic regulation by considering the effect of transfer stations. Kampczyk et al. (2020) presented a study on the second difference in rail temperature of a continuous welded rail.

The tables 2 and 3 and their respective discussions try to show neutral objective evidence about the impact of the research activities carried out by PRERG through their citations by other authors. In the world academia, the impact by scientists is usually measured by an academic metric as their citations. The citations represent the dissemination of knowledge among scientists. It is a way to understand how much our scientific work may have had an impact if at all.

Characterization of Panama Metro Line 1

According to Pyrgidis (Pyrgidis, 2016), rail transport systems can move at grade, underground, and above the ground (elevated). The characterization of Panama Metro Line 1 was possible thanks to a research project of the same manner (Berbey-Álvarez et al., 2011). The general objective of this project was conducted using a framework of academic and research activities about the Panama Metro Line 1 project. In this work, a methodology was proposed on the time estimation of train movement partial services of the Panama Metro Line 1. First, nominal train services were estimated as the basis for estimating partial train services. For this reason, members of the Panama Railway Engineering Research Group (PRERG) considered technical information of the conceptual engineering about the Panama Metro Line 1. This conceptual engineering, functional, technical, and contractual specification corresponded to:

- Conceptual operation engineering (Secretaría del Metro de Panamá, 2010b) (Republica de Panama & Consorcio linea 1, 2010)
- Railway track systems and geometric conceptual design(Secretaría del Metro de Panamá, 2010a)
- Signaling and train control (Metro de Panamá, 2010)
- Rolling stock (Metro de Panama, 2010)(SMP. Secretaria del Metro de Panamá., 2010)(Secretaria del Metro de Panama, 2010)
- Railway stations' architecture (Secretaria del Metro de Panamá(2010), 2010)

- Railway stations' conceptual design (J. Velasco, Fernandez, et al., 2010c, 2010a, 2010b; J. Velasco, J. Fernandez, et al., 2010)

To validate this proposal, results were simulated using a set of scenarios that characterized the proposed model. The cause of the partial train's services could be an incidence, failure, breakdown of rolling stock, rail break, damage to the catenary, etc. This work would be limited to partial train's services because of the temporary immobilization of a train on the railway track.

Finally, PRERG published a paper as result of this project. It was used as a supporting tool for the active teaching and learning methodology in railway engineering courses (A. Berbey-Alvarez et al., 2015).

Dwelling Times, Fuzzy Logic, and AI

Matters around station dwelling times can be tackled with fuzzy logic and AI because the fuzzy set theory provides the mathematical technique for the systematic handling of imprecise data (Leonardi, 2016). In other words, Menéndez et al. (Menéndez et al., 2016) considered that fuzzy logic has become a successful approach to address complex problems. Fuzzy logic succeeds in formulating human knowledge and expert experience for the decision-making process. This allows for the managing and representation of imprecise information and vagueness found in the context of the railway industry. For example, the estimation of station dwelling time is critical for an acceptable railway timetable plan (Kikuchi & Miljkovic, 1999) because the line capacity in metro and high-frequency suburban railways is determined by both station dwelling times and factors like line speed or train acceleration (Berbey-Alvarez, Sanchez, Caballero, & Calvo, 2014). Fuzzy logic is based on observations using decisions based on imprecise and nonnumerical information. Fuzzy models are mathematical equations that represent imprecise information in which the correct values of these variables are real numbers between 0 and 1.

PRERG presented a new approach that combines the origin destination matrices method with the application of fuzzy logic using the Panama Metro Line 1 as a case study. PRERG presented an extension and practical application of previous research, using three fundamental levels of passenger flow in the membership function for a train's coach. Finally, PRERG proposed the application of the proposed algorithm to predict more realistic effects.

The works of Berbey-Alvarez et al. (2014) were cited by many authors, including Oh et al. (Oh et al., 2020), Cristóbal et al. (Cristóbal et al., 2018), Yang, Shiwakoti, and Tay (Yang et al., 2019), Feng et al. (Feng et al., 2017), Van-Ma et al. (Van-Ma et al., 2017), Becker and Schreckenberg (2018), Fabian, Sánchez-Martínez, and Attanucci (Fabian et al., 2018), D'Acierno et al. (D'Acierno et al., 2017), Carvajal, Cucala, and Fernández (Carvajal et al., 2016), He, Zhang, Keyu, and Lu (He et al., 2019), Li, Huang, and Schonfeld (Li et al., 2018), Di Maio, Botte, Montella, and D'Acierno (Di Maio et al., 2020). The summary of the citations are presented in Table 3.

For example, Oh et al. (Oh et al., 2020) presented a case study about dwelling time estimation using real-time train operations and smart card-based passenger data in Seoul, South Korea. Cristobal et al. (2018) presented an article about applying time-dependent attributes to represent demand in road mass transit systems. Yang et al. (2019)'s study explored train dwell time models as developed in the last 40 years. Feng et al. (2017) presented an algorithm by optimizing the energy-efficient metro train timetable and control strategy in off-peak hours. Van-Ma et al. (2017) developed a study about a fuzzy-based adaptive streaming algorithm for reducing entropy rate of an ASH bitrate fluctuation to improve mobile quality of service. Becker and Schreckenberg (2018) presented a case study on the influence

Table 3. Summary of citations by other authors

Authors	Year	1	2	3	4	5	6	7	Institution, University, or Center
Oh et al.	2020	X					x		Korea University, Khalifa University of Science and Technology, Abu Dhabi, Korea Railroad Research Institute
Cristobal et al.	2018	X							University of Las Palmas de Gran Canaria (Spain)
Yang et al.	2019	X		x					RMIT University, Melbourne (Australia)
Feng et al.	2017	X	x						Central South University (China), Beijing Jiaotong University (China)
Van-Ma et al.	2017					x			Chonnam National University (Korea), Electronics and Telecommunications Research Institute (Korea)
Becker & Schreckenberg	2018	X					x		Universität Duisburg-Essen Physik von Transport und Verkehr (Germany)
Fabian et al.	2018	X	x				x		Massachusetts Institute of Technology, Cambridge (USA), Massachusetts Bay Transportation Authority, Boston (USA)
D'Acierno et al.	2017	X					x		University of Naples (Italy), D'Appolonia
Carvajal et al.	2016				X	x			Institute for Research in Technology, Pontifical Comillas University (Spain)
He et al.	2019							x	Southwest Jiaotong University (China), National United Engineering Laboratory of Integrated and Intelligent Transportation (China), China Railway Economic and Planning Research Institute (China)
Li et al.	2018	X							Beijing Jiaotong University (China), University of Maryland (USA)
Di Maio et al.	2020	X							Federico II University of Naples (Italy)
1: Timetable, passenger flow, dwell time; 2: Train's control; 3: Review; 4: Energy consumption; 5: Fuzzy logic; 6: Case study; 7: Machine learning									

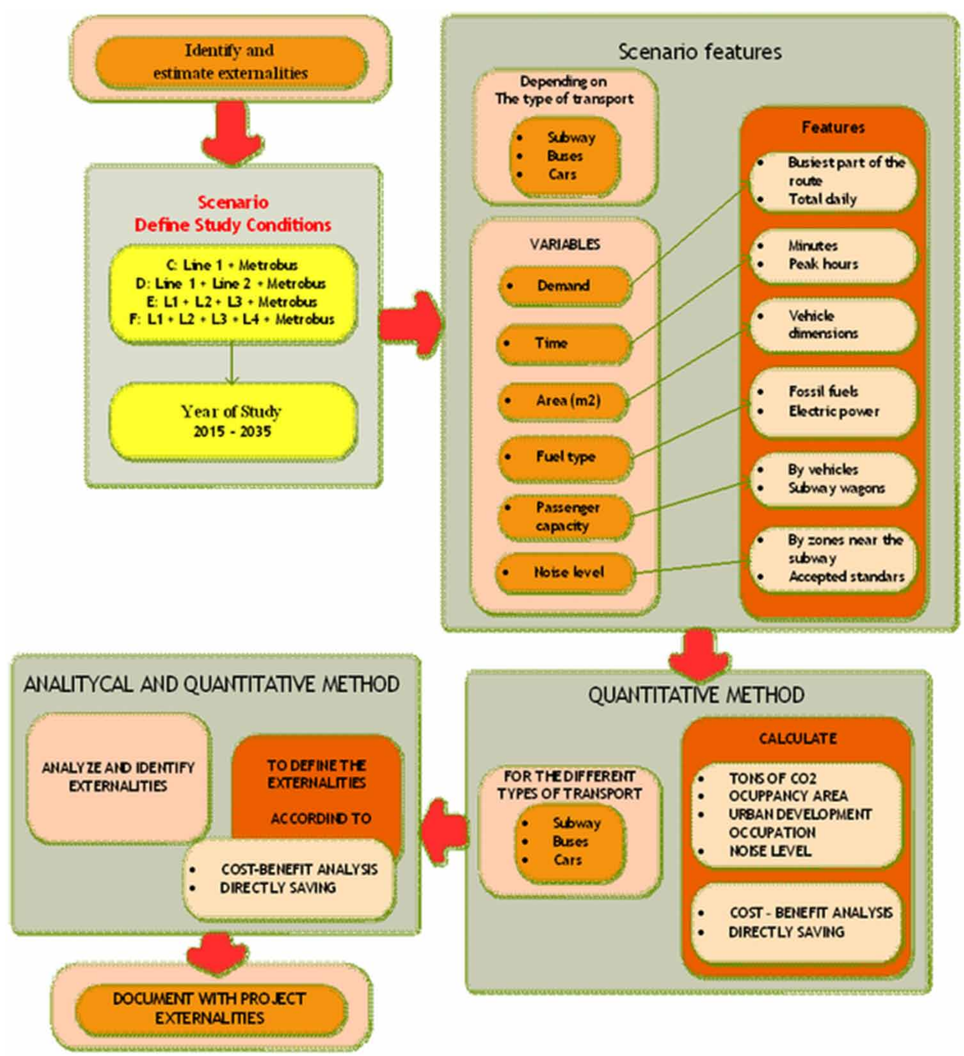
of stochastic dwell times on railway traffic simulations. Fabian et al. (2018) presented a study featured in Improving High-Frequency Transit Performance Through Headway-Based Dispatching: Development and Implementation of a Real-Time Decision-Support System on a Multi-Branch Light Rail Line. D'Acierno et al. (2017) developed a methodology for determining dwell times consistent with passenger flows in the case of metro services. Carvajal et al. (2016) used AI techniques like fuzzy logic and the fuzzy train tracking algorithm for the energy efficient operation of CBTC equipped metro lines. He et al. (He et al., 2019) developed a machine-learning-based integrated pedestrian facilities planning and staff assignment problem in transfer stations. Li et al. (Li et al., 2018) presented a study about metro timetabling for time-varying passenger demand and congestion at stations. Di Maio et al. (Di Maio et al., 2020) presented an analytical formulation to determine each bus stop's corresponding dwell time to increase the reliability of the planned service.

Social-Economics Railway Externalities

The externalities concept corresponds to the cost that affects a third party who did not pay for this benefit. For example, in the case of railway transportation, externalities occur when the consumption of a transportation service private price equilibrium cannot reflect real costs for the general society. Types of railway externalities can include social, economic, environmental, and energy. Externalities can be either positive or negative.

Vehicle congestion in cities, which produces an annual loss of millions of dollars, affects productivity sensitively. The social benefits of mass transit systems have a positive impact on the dynamics of metropolitan areas. Berbey-Alvarez et al. (2017) presented a railway externalities study related to the saving of travel time and economic utility. This study operated under various projected scenarios and compared with real data of passenger mobilization of the Panama Metro Line 1 (2014-2016). It discussed an estimation on the saving of travel times and economic utility through 2035 in Panama City. According to ResearchGate, the study has 850 reads. Figure 1 reveals a general scheme of this methodology by estimated social, economic, and environmental externalities (Guevara-Cedeño, 2013).

Figure 2. Methodology of externalities (Guevara-Cedeño, 2013)



Environmental Railway Externalities

The methodology to determine carbon dioxide (CO_2) emissions for Panama Metro Line 1 was based on the original (American Public Transportation Association, 2009) approach of the APTA climate change standards working group. The APTA methodology calculates the average cost of taking public transit by determining the cost of an average monthly transit pass of local public transit agencies across the country (American Public Transportation Association, 2020).

Berbey-Alvarez et al. (2017, 2019) and Guevara-Cedeño, Aguilar, Torabi, and Berbey-Alvarez (Guevara-Cedeño et al., 2018) published an analysis of CO_2 emissions in the Panama Metro Line 1 using the APTA methodology (2015-2017). Their work has been used as reading and assessment materials in individual short exams (Berbey-álvarez, 2017; Aranzazu Berbey-Alvarez, 2014) in railway engineering courses in the Technological University of Panamá.

RELATIONSHIP BETWEEN RESEARCH ACTIVITY AND TEACHING OF RAILWAY ENGINEERING IN PANAMA

A Global Brief of Railway Engineering in Higher Education

In the LAC context, Kohon (Kohon, 2011) published a study on Latin America's railway transportation sector.Kohon's (2011) study, a technical note financed by the IDB, considered railway training a priority. According to Kohon (2011), the training of new generations of human resource experts was still insufficient. In the field of public management, the training involved professionals in the development of strategies, policies, planning, and regulations associated with rail transportation. In the field of railway companies, the training involved professionals and technicians of medium and higher levels. Kohon (Kohon, 2011) mentioned that initiatives in Argentina and Brazil are limited to the field of railway companies. In addition to strengthening these initiatives, they must consider the possibility of training resources from countries that, for reasons of scale, cannot generate their own training.

However, this situation is not exclusive to the LAC regionLautala et al. (2010) and Lautala, Tyler-Dick, Mckinney, and Clarke (2013) considered that the national emphasis on highway transportation and lack of demand for graduates in rail-related fields led to decades of neglect surrounding rail transportation and engineering education by universities in the United States. However, the Tuning Transatlantic Cooperation in Rail Higher Education (TUNRail) project evaluates teaching and learning practices of railway systems in European and U.S. institutions of higher education by defining the level of collaboration between the academic programs and railway industry (Marinov et al., 2011).

Kalidova and Neduzha (Kalivoda & Neduzha, 2017) presented a study about enhancing the scientific level of engineering training of railway transport professionals. This study confirmed that international cooperation promotes the strengthening of contacts between universities, improves the quality of students' training, is a factor the professional development of future specialists, and raises the scientific level of engineering training of railway transport specialists.

Rizzetto et al. (2015) presented other interesting European experiences regarding a postgraduate course titled "Railway Infrastructure and Systems Engineering." This postgraduate course is a case of cooperation between academia and railway industry transport. Lautala (Lautala, 2007) presented a benchmarking study to investigate the upcoming demand for university graduates by Class I railroads and engineering consultants. The study looked at whether current methods are adequate to attract, educate, recruit, train, and retain engineering students in the railroad profession.

Lautala and Tyler-Dick (2017) presented the results of the Railway Engineering Education Symposium (REES). Marinov et al. (Marinov et al., 2013) analyzed the current state of supply and demand for higher education in rail logistics. Their work revealed a spectrum of courses and programs related to rail, freight transport, and logistics.

There is still a strong need for specific training and education on operations management skills. These skills will improve company performance, efficiency, and quality of service.

Jing, You-Ming, and Li-Yan (2017) proposed a revised method based on education professional certification standards. Its curriculum, which was based on the supplementary standard of engineering certification, aimed to improve the capacity of staff in the rail transit operation. Another curricular review experience is presented in Kaewunruen (Kaewunruen, 2017). The railway engineering curriculum in the civil engineering program was critically reviewed and evaluated, enhancing core technical skills alongside those required for systems-thinking solutions. Comparative evaluations were based on the review and evaluation of both the academic and railway industry sectors.

Railway Engineering in Panamaniam Higher Education

In 2009, Berbey-Alvarez et al. (2009) founded the PRERG) at the Technological University of Panamá. This group included members of Spain. It later incorporated members of the University of Granada, Spain. The PRERG was founded in its long-term vision and growth of the railway engineering professional workforce in Panama.

According to Streitzig, Schön, Griese, and Oetting (Streitzig et al., 2013), education is a central aspect for winning and qualifying employees for railway operation and research. According to Tyler-Dick, Schlake, and Lautala (2018) and Tyler-Dick, Lautala, and Schlake (2019), students must be introduced to railway concepts before they decide on the direction of their studies. In doing so, student interest in rail courses will increase and, in turn, satisfy industry demands for interns. The tables 4 and 5 summarize efforts of railway engineering teaching at the Technological University of Panamá.

The PRERG work generated by the research and development (R&D) activity has been used as a supporting tool for the active teaching and learning methodology in a railway engineering course. Table 5 shows a resume of the engineering course oriented to railway and engineering transportation.

Table 4. Summary of railway engineering seminaries

Speaker´s Affiliation	Title	Year	Sponsors
Technological University of Panamá Universidad Politécnica de Madrid	*Sistemas y Tecnologías de Transporte Urbano Ferroviario*	2010	Aecid, Metro de Panamá, UTP
Universidad Tecnológica de Panamá Universidad de Granada	*Sistema de Ingeniería Ferroviaria I*	2014	AUIP, Metro de Panama, UTP
Universidad Tecnológica de Panamá Universidad de Granada	*Diseño geométrico y mecánica de la vía férrea*	2015	UTP

Source: (Calvo-Poyo & Berbey-Álvarez, 2014), (Lorente-Gutierrez & Berbey-Álvarez, 2015), Sanz-Bobi, Berbey-Álvarez, Caballero, and Alvarez (2009), (Sanz-Bobi et al., 2009, 2010)

Table 5. Resume of engineering course oriented to railway and engineering transportation

Group	Subject	Students	Year
1IE141	Tópicos de actualización tecnológica	39	2014
1IE143	Tópicos de actualización tecnológica	37	2014
1IE143	Tópicos de actualización tecnológica	39	2015
1IE141	Tópicos de actualización tecnológica	39	2016
1IE143	Tópicos de actualización tecnológica	39	2017

Source: (Vicerrectoría académica, 2020)

Engineering students were able to better comprehend the Panama Metro Network through the use of Panama Metro professional technical documents related to Lines 1 and 2. However, these resources must be adapted through a stronger understanding by engineering students. Therefore, it is important that the railway engineering professors have a solid background. Railway engineering backgrounds should include three components: (1) higher engineering education; (2) R&D; and (3) professional activities in the railway industry.

In the same direction, a group of papers regarding railway engineering education in undergraduate engineering courses was published (Berbey-álvarez et al., 2017; A Berbey-Alvarez, 2015; A Berbey-Alvarez et al., 2018; Berbey Álvarez, 2016). With the objective of developing the R&D activity with engineering students, Berbey-Alvarez developed a final subject project guide (Berbey-Álvarez, 2017; A Berbey-Alvarez, 2019) so engineering students could present scientific posters and articles in congress (Alvarado et al., 2012; Cogley-Brown, Berbey Álvarez, et al., 2014; Cogley-Brown, Berbey-Alvarez, et al., 2014; Monrroy, 2018). Consequently, regarding the PRERG's activities, the scientific papers generated by the R&D activity were used as supporting tools for the active teaching and learning methodology in railway engineering courses at the Technological University of Panamá, particularly in the faculty of electrical engineering. For example, Monrroy's (2018) scientific paper on the main characteristics of the electrical system of the Panama Metro Line 2 was published with electromechanical engineering students. Important points were developed, including substations, catenary systems, cables, protection systems, power supply systems, and other electrical aspects of the rail transportation system. Therefore, it is possible to construct a didactic resource with and by students of engineering and related careers in the courses of engineering and rail transportation.

Table 6 shows the citations of Berbey et al. (Berbey et al., 2013), (Berbey-álvarez et al., 2017), and (A Berbey-Alvarez & Caballero-George, 2012). The table's citations often correspond to bachelor's theses and scientific papers presented in congress. These citations represent the dissemination of knowledge among both undergraduate and graduate students. Our citation in master thesis, bachelor thesis and scientific papers in congress is a sample of how much our scientific work in PRERG has had an impact.

Additionally, the faculty of civil engineering's subject, Terminales de Trasbordo (Cod. 8771)" is designed for bachelor's students in maritime port engineering (UTP, 2016e). In the field of Panamanian private universities, the "Universidad Interamericana de Panamá" (UIP) includes a subject titled "Transporte Terrestre y Ferroviario" (code 202-00009) in cycle 7 of the bachelor's degree in transportation and logistics engineering (UIP, 2019).

Table 6. Summary of citations of PRERG

Works	Authors	Year	1	2	3	Institution, University, Center
(Berbey et al., 2013)	Sarmiento	2020	x			Universidad de Buenos Aires (Argentina)
	Conde	2017	x			Universidad de San Andres (Argentina)
	Amaya-Usaquen	2015		x		Universidad Piloto de Colombia (Colombia)
	Muñoz-Portero	2016		x		Universidad Carlos III de Madrid (Spain)
	Madrid-Naz	2018		x		Universidad de Sevilla (Spain)
	Doicela-Gómez	2018		x		Universidad Central de Ecuador (Ecuador)
	Berrezueta-Merchan	2016		x		Universidad Politecnica Salesiana (Ecuador)
(Berbey-álvarez et al., 2017)	Carretón et al.,	2018			x	Universidad de Las Palmas de Gran Canaria (Spain)
Berbey et al. (2012)	Amaya-Usaquen	2015			x	Universidad Piloto de Colombia (Colombia)
(Berbey et al., 2010)	Benavides et al.,	2017			x	Universidad técnica de norte (Ecuador)
Berbey-Alvarez & Caballero-George (2012).	Alzate-Torres et al.,	2018			x	Universidad Nacional de Colombia (Colombia)
(1); Master's thesis, (2): Bachelor's thesis, (3): Scientific paper						

Railway Professional and Technical Training in Panama

The Instituto Técnico Superior de Panamá Oeste (ITSPO) provides railway training for professional and technical skills (Richards, 2016). The ITSPO installed a railway track section and a tramway to develop these professional skills (Presidencia de la República de Panamá, 2017)(Ministerio de Educación, 2016) (Zeballos, 2016). The ITSPO was created by a cooperation and technical assistance agreement in the field of education between the Ministries of Education of Panama (MEDUCA) and France. According to MEDUCA, three companies support this railway professional and technical training (Ministerio de Educación, 2016). First, Alstom donated the rolling stock. Second, the TSO CIM company built a railway track section so students can complete their hours of laboratory practice. Third, Schneider Electric donated the educational equipment for electricity and industrial automation.

REGIONAL FUTURE TRENDS

This section presents a brief vision about future and emerging regional trends. It explores railway engineering projects like the Panama Monorail Line 3, Maya Train, Bogota Metro, and Mesoamerican Train.

The Panama Metro Network operates Lines 1 and 2 in Panama City. The next railway, Line 3, is a monorail that departs from Albrook Station before traveling to Arraiján, Nuevo Chorrillo, and Ciudad del Futuro. The first phase corresponds to 26.7 kilometers and 14 stations (Martínez-Palacios, 2019). Phase one's estimated demand is 20,000 passengers in one direction at peak hours. Each train will have six wagons. Line 3 will have two circuits: East Circuit (Albrook – Nuevo Chorrillo [17.5km]) and Complete Circuit (Albrook – Ciudad del Futuro [25.85km]) (Metro de Panamá, 2020a).

The Maya Train will be a 1,525 kilometer railway line in Mexico's Yucatan Peninsula. It will cross the states of Tabasco, Campeche, Chiapas, Yucatan, and Quintana Roo. This railway line will have 17 stations with rolling stock to provide cargo and passenger transportation services. The maximum speed of the passenger rolling stock will be 160 kilometers per hour (Comisión de asuntos frontera sur, 2019; Flores et al., 2019; Mexico., 2020) (Martínez-Palacios, 2019).

The Mesoamerican Train, connecting Mexico with Panama (Rieles multimedio, 2020), is part of the Mesoamérica project, integrated by Mexico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, Colombia, and the Dominican Republic. The project includes a portfolio of projects in eight strategic areas: (1) energy; (2) transport; (3) telecommunications; (4) commercial facilitation and competitiveness; (5) health; (6) environment; (7) risk management; and (8) housing (EFE, 2013).

The Bogota Metro Line 1 will be a 23.96 kilometer elevated mass rapid transit line. Bogota Metro Line 1 will accommodate 72,000 passengers per hour in each direction. The trains will achieve an average speed of 43 kilometers per hour, reaching the south from the north in approximately 27 minutes (Metro de Bogotá, 2015; Verdict media, 2022).

Dussel-Peters, Armony, and Cui (Dussel-Peters et al., 2018) examined the connections between China and the LAC. Their research showed the expansion of an emerging field of study, including significant implications for the future relationship between China and Latin America. In the future, the railway transportation systems and other LAC infrastructure developments will play a critical role (Koleski & Blivas, 2018).

CONCLUSION

Rail mobility, including the application of AI, can solve problems related to urban massive transit and freight cargo. There is extensive scientific literature on the multiple applications of AI techniques in the railway transportation system. Fuzzy logic, a key tool, models expert knowledge to improve the decision-making process as a consequence of more adequately representing imprecise information and vagueness in the railway industry. The methods addressed demonstrate the application of technologies for solving pollution and economic problems in rail transport, which are means of human development.

Railway engineering should have a relevant place within university curricula and engineering disciplines. For example, railway engineering courses should be part of curricula design within civil engineering, computer engineering, electrical engineering, mechanical engineering, industrial engineering, telecommunications engineering, and others.

The authors have been able to contribute knowledge in the development of railway studies for Panama and in the research community. At present, the PRERG continues with research railway engineering activities. In addition, the female leader of this research group has submitted her first book for publication, titled *Fundamentos de la Ingeniería ferroviaria: la vía* (Editorial Tecnologica of the Technological University of Panamá).

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KEY TERMS AND DEFINITIONS

Algorithm: Is a set of well-defined rules in a procedure with the objective to find a corrected solution of a problem.

Artificial Intelligence: A branch of computer sciences engineering performs tasks like visual perception, speech recognition, decision making, and translation between languages. This allows a computer program to think and learn like intelligent agents.

Blocking Time: Is the period in which a section track authorized the use of one train and the section track is blocked to all other trains.

Control Trains: Is an engineering system for monitoring and controlling train movement's support to train protection system.

Delay: Is a time deviation of a train with respect your original timetable.

Dwelling Time: Is a period when a train stops in a railway station until the train moves again to the next station.

Externalities: The externalities concept corresponds to the cost that affects a third party who did not pay for this benefit. For example, in the case of railway transportation, externalities occur when the consumption of a transportation service private price equilibrium cannot reflect real costs for the general society. Types of railway externalities can include social, economic, environmental, and energy. Externalities can be either positive or negative.

Fuzzy Logic: Is based on observations using decisions based on imprecise and nonnumerical information. Fuzzy models are mathematical equations that represent imprecise information in which the correct values of these variables are real numbers between 0 and 1.

Headway: The time distance between two successive trains on the railway track.

Railway Engineering: Is a multidisciplinary engineering discipline focused on the design, construction, operation, inspection, and evaluation of rail transportation systems like metro, railroad, commuter train, tramway, light rail, and monorail. This high-tech discipline includes a range of engineering disciplines like civil engineering, computer engineering, electrical engineering, mechanical engineering, industrial engineering, telecommunications engineering, and railway externalities.

Recovery Time: Is a period to correct small delays in the trains.

Stability: The capacity of any system to recover its original state.

Station: According UIC 406, is a point of a railway network where the train can overtake, crossing or running in reverse direction. The station is a defined place where the trains stop to passengers leave it.

Train Diagram: Is a distance-time graphic where is showed the train paths, running times, dwelling time on a railway line.