Vehicle and crew scheduling for urban bus lines

1. Year: 2006
2. Journal: European Journal of Operational Research
3. Authors: Rodrigues, Maikol M. and {De Souza}, Cid C. and Moura, Arnaldo V.

> A solution to the urban transportation problem is given by vehicle and crew schedules. These schedules must meet the passenger demand and satisfy technical and contractual restrictions stemming from the daily operation of the lines, while optimizing some measure of operational cost. This work describes a computational tool developed to solve the urban transportation problem in the large metropolitan area of S{~{a}}o Paulo, Brazil. The techniques used are based on integer programming models coupled with heuristics. The former produces good feasible solutions, and the latter improves the quality of the final solutions. While the operational and labor restrictions are specific to the city of S{~{a}}o Paulo, the same ideas can inspire similar approaches for solving the urban transportation problem arising in other metropolitan areas. {\textcopyright} 2004 Elsevier B.V. All rights reserved.

Transit network timetabling and vehicle assignment for regulating authorities

1. Year: 2010
2. Journal: Computers and Industrial Engineering
3. Authors: Guihaire, Val{'{e}}rie and Hao, Jin Kao

> In the literature on transit planning, network timetabling and vehicle scheduling are usually treated as separate problems. In this paper, we focus on combining important features of these two steps and propose a simultaneous solution approach to redefine timetables with the objective of bringing improvements to both quality of service and vehicle costs incurred. This includes the objectives of quantity and quality of the transfers proposed, evenness of the line headways, fleet size and length of the deadheads. The model proposed for this simultaneous approach is adapted to the problem faced by regulating authorities, encouraging intermodality and taking into account a variety of practical features. We introduce an optimization procedure based on Iterated Local Search and present computational experiments carried out on data from a large existing transit network, showing substantial improvements in both quality of service and level of resources compared to the current practice. {\textcopyright} 2010 Elsevier Ltd. All rights reserved.

Optimal multi-vehicle type transit timetabling and vehicle scheduling

1. Year: 2011
2. Journal: Procedia - Social and Behavioral Sciences
3. Authors: Ceder, Avishai

> The public-transport (transit) operation planning process commonly includes four basic activities, usually performed in sequence: network design, timetable development, vehicle scheduling, and crew scheduling. This work addresses two activities: timetable development and vehicle-scheduling with different vehicles types. Alternative timetables are constructed with either even headways, but not necessarily even passenger loads or even average passenger loads, but not even headways. A method to construct timetables with the combination of both even-headway and even-load concepts is developed for multi-vehicle sizes. The vehicle-scheduling problem is based on given sets of trips and

> vehicle types arranged in decreasing order of vehicle cost. This problem can be formulated as a cost-flow network problem with an NP-hard complexity level. Thus, a heuristic algorithm is developed. A few examples are used as an expository device to illustrate the procedures developed. {\textcopyright} 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of the Organizing Committee.

Optimal deployment of public charging stations for plug-in hybrid electric vehicles

1. Year: 2013
2. Journal: Transportation Research Part B: Methodological
3. Authors: He, Fang and Wu, Di and Yin, Yafeng and Guan, Yongpei

> This paper develops an equilibrium modeling framework that captures the interactions among availability of public charging opportunities, prices of electricity, and destination and route choices of plug-in hybrid electric vehicles (PHEVs) at regional transportation and power transmission networks coupled by PHEVs. The modeling framework is then applied to determine an optimal allocation of a given number of public charging stations among metropolitan areas in the region to maximize social welfare associated with the coupled networks. The allocation model is formulated as a mathematical program with complementarity constraints, and is solved by an active-set algorithm. Numerical examples are presented to demonstrate the models and offer insights on the equilibrium of the coupled transportation and power networks, and optimally allocating resource for public charging infrastructure. {\textcopyright} 2012 Elsevier Ltd.

An integrated approach for timetabling and vehicle scheduling problems to analyze the trade-off between level of service and operating costs of transit networks

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ibarra-Rojas, Omar J. and Giesen, Ricardo and Rios-Solis, Yasmin A.

> In transit systems there is a critical trade-off between the level of service and operating costs. At the planning level, for a given network design, this trade-off is captured by the timetabling (TT) and vehicle scheduling (VS) problems. In the TT problem we try to maximize the number of passengers benefited by well timed transfers, while in the VS problem we seek to minimize the operating costs, which are related to the fleet size. This paper presents two integer linear programming models for the TT and VS problems, and combines them in a bi-objective integrated model. We propose and implement an {small element of}-constraint method to jointly solve this TT and VS bi-objective problem. This allows to analyze the trade-off between these two criteria in terms of Pareto fronts. Numerical experiments show that our proposed approach can solve scenarios with up to 50 bus lines.

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Integrated timetabling and vehicle scheduling with balanced departure times

1. Year: 2015
2. Journal: OR Spectrum
3. Authors: Schmid, Verena and Ehmke, Jan Fabian

> Sequential planning of public transportation services can lead to inefficient vehicle schedules. Integrating timetabling and vehicle scheduling, the vehicle scheduling problem with time windows (VSP-TW) aims at minimizing costs of public transport operations by allowing small shifts of service trips' departure times. Within the scope of tactical planning, a larger flexibility of departure times following predefined departure time windows may be desirable. However, with increasing degrees of freedom, conventional solution approaches for the VSP-TW become computationally prohibitive. Furthermore, a sole focus on cost minimization might produce timetables of insufficient quality, while public transport agencies expect high-quality timetables with service trips scheduled at times reasonable from a passenger's point of view. Extending the VSP-TW, we propose the vehicle scheduling problem with time windows and balanced departure times (VSP-TW-BT). In addition to the cost-efficiency objective of the VSP-TW, our objective function considers the quality of a timetable from a passenger's point of view. Timetables are generated by balancing consecutive departures on a line according to predefined departure time intervals. We use a weighted sum approach to combine both objectives, namely costs of operation and quality of timetables. Our mathematical model and solution approach are based on efficient techniques known from the area of vehicle routing with time windows. A hybrid metaheuristic framework is proposed, which decomposes the problem into a scheduling and a balancing component. Real-world-inspired instances allow for the evaluation of quality and performance of the solution approach. The proposed solution approach is able to outperform a commercial solver in terms of run time and solution quality.

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Planning, operation, and control of bus transport systems: A literature review

1. Year: 2015
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ibarra-Rojas, O. J. and Delgado, F. and Giesen, R. and Mu{~{n}}oz, J. C.

> The efficiency of a transport system depends on several elements, such as available technology, governmental policies, the planning process, and control strategies. Indeed, the interaction between these elements is quite complex, leading to intractable decision making problems. The planning process and real-time control strategies have been widely studied in recent years, and there are several practical implementations with promising results. In this paper, we review the literature on Transit Network Planning problems and real-time control strategies suitable to bus transport systems. Our goal is to present a comprehensive review, emphasizing recent studies as well as works not addressed in previous reviews.

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Integrating timetabling and crew scheduling at a freight railway operator

1. Year: 2016
2. Journal: Transportation Science
3. Authors: Bach, Lukas and Dollevoet, Twan and Huisman, Dennis

> We investigate to what degree we can integrate a train timetabling/engine scheduling problem with a crew scheduling problem. In the timetabling/engine scheduling problem, we determine for each demand a specific time within its time window when the demand should be serviced. Furthermore, we generate engine duties for the demands. In our solution approach for the overall problem, we first obtain an optimal solution for the timetabling/engine scheduling problem. When solving the crew scheduling problem, we then exploit the fact that numerous optimal and near optimal solutions exist for the previous problem. We consider all these solutions that can be obtained from the optimal engine schedule by shifting the demands in time, while keeping the order of demands in the engine duties intact. In particular, in the crew scheduling stage it is allowed to retime the service of demands if the additional cost is outweighed by the crew savings. This information is implemented in a mathematical model for the crew scheduling problem. The model is solved using a column generation scheme. We perform computational experiments based on a case at a freight railway operator, DB Schenker Rail Scandinavia, and show that significant cost savings can be achieved.

An eigenmodel for iterative line planning, timetabling and vehicle scheduling in public transportation

1. Year: 2017
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Sch{"{o}}bel, Anita

> Planning a public transportation system is a multi-objective problem which includes among others line planning, timetabling, and vehicle scheduling. For each of these planning stages, models are known and advanced solution techniques exist. Some of the models focus on costs, others on passengers' convenience. Setting up a transportation system is usually done by optimizing each of these stages sequentially. In this paper we argue that instead of optimizing each single step further and further it would be more beneficial to consider the whole process in an integrated way. To this end, we develop and discuss a generic, bi-objective model for integrating line planning, timetabling, and vehicle scheduling. We furthermore propose an eigenmodel which we apply for these three planning stages and show how it can be used for the design of iterative algorithms as heuristics for the integrated problem. The convergence of the resulting iterative approaches is analyzed from a theoretical point of view. Moreover, we propose an agenda for further research in this field.

Locating charging infrastructure for electric buses in Stockholm

1. Year: 2017
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Xylia, Maria and Leduc, Sylvain and Patrizio, Piera and Kraxner, Florian and Silveira, Semida

> Charging infrastructure requirements are being largely debated in the context of urban energy planning for transport electrification. As electric vehicles are gaining momentum, the issue of locating and securing the availability, efficiency and effectiveness of charging infrastructure becomes a complex question that needs to be addressed. This paper presents the structure and application of a model developed for optimizing the distribution of charging infrastructure for electric buses in the urban context, and tests the model for the bus network of Stockholm. The major public bus transport hubs connecting to the train and subway system show the highest concentration of locations chosen by the model for charging station installation. The costs estimated are within an expected range when comparing to the annual bus public transport costs in Stockholm. The model could be adapted for

> various urban contexts to promptly assist in the transition to fossil-free bus transport. The total costs for the operation of a partially electrified bus system in both optimization cases considered (cost and energy) differ only marginally from the costs for a 100% biodiesel system. This indicates that lower fuel costs for electric buses can balance the high investment costs incurred in building charging infrastructure, while achieving a reduction of up to 51% in emissions and up to 34% in energy use in the bus fleet.

Multi-objective integration of timetables, vehicle schedules and user routings in a transit network

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Laporte, Gilbert and Ortega, Francisco A. and Pozo, Miguel A. and Puerto, Justo

> The Transit Network Timetabling and Scheduling Problem (TNTSP) aims at determining an optimal timetable for each line of a transit network by establishing departure and arrival times at each station and allocating a vehicle to each timetable. The current models for the planning of timetables and vehicle schedules use the a priori knowledge of users' routings. However, the actual route choice of a user depends on the timetable. This paper solves the TNTSP in a public transit network by integrating users' routings in the model. The proposed formulation guarantees that each user is allocated to the best possible timetable, while satisfying capacity constraints. In addition, we perform a trade-off analysis by means of a multi-objective formulation which jointly optimizes the operator's and the users' criteria.

Optimal Traffic-Power Flow in Urban Electrified Transportation Networks

1. Year: 2017
2. Journal: IEEE Transactions on Smart Grid
3. Authors: Wei, Wei and Mei, Shengwei and Wu, Lei and Shahidehpour, Mohammad and Fang, Yujuan

> This paper conducts an interdisciplinary study on the coordinated operation of both transportation system and power system. We consider an electrified transportation network enabled by wireless power transfer technology and coupled with a power distribution network (PDN) in the future city. The independent system operator, which is a public entity, is eligible to manage generation assets and charge congestion tolls (CTs) on electrified roads with the purpose of minimizing social cost. The route choices of electric vehicles are amenable to the Wardrop user equilibrium (UE) principle, such that no one can reduce his travel cost by changing route unilaterally. The traffic UE pattern further influences the spatial distribution of the electrical loads of the PDN. The power flow of the PDN is modeled through Dist-Flow equations. To find out the best generation schedule and CTs, we propose an optimal traffic-power flow model, which is a mixed integer nonlinear program with traffic UE constraints and further reformulated as a mixed integer second-order cone program, whose global optimal solution is accessible with reasonable computation effort. Case studies corroborate the benefits from the joint operation of the coupled networks, and demonstrate that ignoring the interdependency between the two critical infrastructures may lead to an insecure operation.

Integrating shared autonomous vehicle in public transportation system: A supply-side simulation of the first-mile service in Singapore

1. Year: 2018

2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Shen, Yu and Zhang, Hongmou and Zhao, Jinhua

> This paper proposes and simulates an integrated autonomous vehicle (AV) and public transportation (PT) system. After discussing the attributes of and the interaction among the prospective stakeholders in the system, we identify opportunities for synergy between AVs and the PT system based on Singapore's organizational structure and demand characteristics. Envisioning an integrated system in the context of the first-mile problem during morning peak hours, we propose to preserve high demand bus routes while repurposing low-demand bus routes and using shared AVs as an alternative. An agent-based supply-side simulation is built to assess the performance of the proposed service in fifty-two scenarios with different fleet sizes and ridesharing preferences. Under a set of assumptions on AV operation costs and dispatching algorithms, the results show that the integrated system has the potential of enhancing service quality, occupying fewer road resources, being financially sustainable, and utilizing bus services more efficiently.

Network equilibrium of coupled transportation and power distribution systems

1. Year: 2018
2. Journal: IEEE Transactions on Smart Grid
3. Authors: Wei, Wei and Wu, Lei and Wang, Jianhui and Mei, Shengwei

> This paper presents a holistic modeling framework for the interdependent transportation network and power distribution network. From a system-level perspective, on-road fast charging stations would simultaneously impact vehicle routing in the transportation system and load flows in the distribution system, therefore tightly couple the two systems. In this paper, a dedicated traffic user equilibrium model is proposed to describe the steady-state distribution of traffic flows comprised of gasoline vehicles and electric vehicles. It encapsulates route selections, charging opportunities, electricity prices, and individual rationalities of minimum travel expense in a convex traffic assignment problem over an extended transportation network. An adaptive path generation oracle is suggested to solve the problem in a tractable manner. Economic operation of the power distribution system is formulated as an alternating current optimal power flow problem. Convex relaxation is performed. The optimal generation dispatch and nodal electricity prices can be computed from a second-order cone program. It is revealed that an equilibrium state will emerge due to the rational behaviors in the coupled systems, which is characterized via a fixed-point problem. A best-response decomposition algorithm is suggested to identify the network equilibrium through iteratively solving the traffic assignment problem and the optimal power flow problem, both of which entail convex optimization. Illustrative examples are presented to validate related concepts and methods.

Optimally combined headway and timetable reliable public transport system

1. Year: 2018
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Varga, Bal{'{a}}zs and Tettamanti, Tam{'{a}}s and Kulcs{'{a}}r, Bal{'{a}}zs

> This paper presents a model-based multiobjective control strategy to reduce bus bunching and hence improve public transport reliability. Our goal is twofold. First, we define a proper model, consisting of multiple static and dynamic components. Bus-following model captures the longitudinal dynamics taking into account the interaction with the surrounding traffic. Furthermore, bus stop operations are

> modeled to estimate dwell time. Second, a shrinking horizon model predictive controller (MPC) is proposed for solving bus bunching problems. The model is able to predict short time-space behavior of public transport buses enabling constrained, finite horizon, optimal control solution to ensure homogeneity of service both in time and space. In this line, the goal with the selected rolling horizon control scheme is to choose a proper velocity profile for the public transport bus such that it keeps both timetable schedule and a desired headway from the bus in front of it (leading bus). The control strategy predicts the arrival time at a bus stop using a passenger arrival and dwell time model. In this vein, the receding horizon model predictive controller calculates an optimal velocity profile based on its current position and desired arrival time. Four different weighting strategies are proposed to test (i) timetable only, (ii) headway only, (iii) balanced timetable - headway tracking and (iv) adaptive control with varying weights. The controller is tested in a high fidelity traffic simulator with realistic scenarios. The behavior of the system is analyzed by considering extreme disturbances. Finally, the existence of a Pareto front between these two objectives is also demonstrated.

A matheuristic for integrated timetabling and vehicle scheduling

1. Year: 2019
2. Journal: Transportation Research Part B: Methodological
3. Authors: Carosi, Samuela and Frangioni, Antonio and Galli, Laura and Girardi, Leopoldo and Vallese, Giuliano

> Planning a public transportation system is a complex process, which is usually broken down in several phases, performed in sequence. Most often, the trips required to cover a service with the desired frequency (headway) are decided early on, while the vehicles needed to cover these trips are determined at a later stage. This potentially leads to requiring a larger number of vehicles (and, therefore, drivers) that would be possible if the two decisions were performed simultaneously. We propose a multicommodity-flow type model for integrated timetabling and vehicle scheduling. Since the model is large-scale and cannot be solved by off-the-shelf tools with the efficiency required by planners, we propose a diving-type matheuristic approach for the problem. We report on the efficiency and effectiveness of two variants of the proposed approach, differing on how the continuous relaxation of the problem is solved, to tackle real-world instances of bus transport planning problem originating from customers of M.A.I.O.R., a leading company providing services and advanced decision-support systems to public transport authorities and operators. The results show that the approach can be used to aid even experienced planners in either obtaining better solutions, or obtaining them faster and with less effort, or both.

Bus and driver scheduling with mealtime windows for a single public bus route

1. Year: 2019
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Kang, Liujiang and Chen, Shukai and Meng, Qiang

> This study deals with the bus & driver scheduling problems with mealtime windows for a single public transport bus route. Firstly, we develop three explicit Integer Linear Programming (ILP) models to formulate: the bus driver scheduling, bus & driver scheduling, and bus & driver scheduling with mealtime windows, respectively. These ILP models enable bus operators to solve their bus & driver scheduling problems by directly invoking an available optimization solver such as IBM ILOG CPLEX. However, our numerical experiments do not show remarkable improvements, as CPLEX takes more

> than 12, 17, and 35 h respectively to reduce the optimality gap to at most 0.5% for solving the above three models in an over 12-hour bus & driver scheduling problem. To improve the computational efficiency, we develop a valid inequality approach that can generate valid cuts incorporating with the CPLEX. An investigation into the valid inequality approach proves its high computational efficiency. In addition, we develop a self-adaptive search method for determining the upper and lower bounds of driver group and bus fleet sizes. Finally, we test our models and approaches on a real round-trip bus route. The results indicate that compared with the only use of CPLEX to solve the above three models, the valid inequality approach can address large-scale instances in a reasonable CPU time.

Fast-charging station deployment for battery electric bus systems considering electricity demand charges

1. Year: 2019
2. Journal: Sustainable Cities and Society
3. Authors: He, Yi and Song, Ziqi and Liu, Zhaocai

> Battery electric buses (BEBs) are considered a promising alternative for bus fleets to alleviate the growing environmental problems in urban areas, and fast-charging technology has been introduced to BEB systems to help electric buses provide uninterrupted service without the need to carry a large onboard battery. The general consensus is that fast-charging may lead to high electricity demand charges, thus compromising the competitiveness of electric bus systems. However, a majority of current electric bus fast-charging station deployment models ignore these charges. The present study addresses this gap by explicitly considering the electricity demand charges in the optimal deployment problem of fast-charging stations for battery electric bus systems. The problem is formulated as a mixed integer linear programming model with the objective of minimizing the total cost of vehicle batteries, fast-charging stations, energy storage systems, and electricity demand charges. Numerical studies based on a real-world bus network in Salt Lake City, Utah, are conducted to demonstrate the effectiveness of the proposed model. The results show that the proposed model can effectively determine the deployment of fast-charging stations, the design of vehicle battery sizes, as well as the installation of energy storage systems. This study demonstrates that energy storage systems are a potential remedy for high demand charges from fast-charging.

Introducing autonomous buses and taxis: Quantifying the potential benefits in Japanese transportation systems

1. Year: 2019
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Abe, Ryosuke

> The introduction of autonomous buses and taxis is expected to generate such benefits as cost reductions—and particularly for regional bus operations with a substantial deficit—as well as enhancing public transit accessibility through decreased trip costs. The purpose of this paper is to provide an overview of the impacts of introducing autonomous buses and taxis on metropolitan transportation systems by quantifying the costs of travel in Japan, and to discuss the potential benefits. First, this study sets the assumptions on autonomous driving technology, including its impacts on vehicle costs, the decreased labor costs for driving and safety monitoring in buses and taxis, and decreased driving stress for private car users. Next, operating costs are computed for autonomous buses and taxis in Japanese metropolitan areas. The costs of travel, or the sum of monetary and time

> costs, are then computed with and without vehicle automation for different trip types in high- and low-density metropolitan areas. The results highlight that the costs of public transit trips that currently have a smaller share of time costs in overall trip costs could decrease considerably due to vehicle automation. For instance, costs for 10–20-km trip lengths could decrease by 44–61% for taxi trips and 13–37% for rail/bus trips with taxi access, followed by a decrease of 6–11% for bus trips and 1–11% for rail trips with bus access. Further, private car trip costs could decrease by 11–16%. More substantial cost reductions in rail/bus trips with taxi access could occur in the case of smaller trip distances and/or in residential areas far from stations; larger reductions in rail trips with bus access could occur in low-density metropolitan areas. Finally, it is expected that vehicle automation in more fixed modes of public road transit could primarily benefit the transit industry and government, with such effects as improved labor productivity and reduced subsidies, while vehicle automation in more flexible modes could benefit metropolitan residents as well as the transit industry. This further suggests that a deficit of regional bus operations could be recovered during the transition to the full performance of autonomous buses.

Multistage large-scale charging station planning for electric buses considering transportation network and power grid

1. Year: 2019
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Lin, Yuping and Zhang, Kai and Shen, Zuo Jun Max and Ye, Bin and Miao, Lixin

> With the applications of electric buses (e-buses), potential solutions to problems related to infrastructures for charging e-buses are emerging. This study particularly focused on large-scale fast charging-station planning for e-buses in the public transportation electrification process, according to the characteristics of e-bus operation and plug-in fast charging mode. We conducted an interdisciplinary study to optimize planning jointly under the transportation system and power grid. In addition to capturing the spatiality of the e-bus charging service network, we further considered temporality in order to conduct long-term planning in view of the continuously growing e-bus charging demand. A spatial-temporal model, which determines the sites and sizes of e-bus charging stations, was proposed and the strategies for multistage infrastructure planning were put forward. The model was equivalently transformed into a mixed-integer second-order cone programming with high computational efficiency. The model and the multistage planning strategies were justified through a series of numerical experiments. A case study of Shenzhen, China was implemented and the robustness of the model to plan changes was studied.

Real-time schedule adjustments for autonomous public transport vehicles

1. Year: 2019
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Cao, Zhichao and Ceder, Avishai (Avi) and Zhang, Silin

> New advanced technologies have made it possible to deal with real-time schedule adjustments of public transport (PT) service. Indeed, using autonomous public transport vehicles (APTVs) prudently can result in significant improvements in the reliability, efficiency, and attractiveness of PT. The lack of human drivers and the feasible control strategies of the APTVs make it possible to offer a reliable, efficient and attractive service that can handle, in real time, the fluctuations in passenger demand. This work assumes that the APTVs of a single line are controlled centrally and are responsive to real-time

> requests from passengers. As the result, a real-time schedule can be constructed and communicated to the passengers. However, during the actual operations, the real-time demand will be fluctuated entailing schedule adjustments. These adjustments are optimized in this work using two operational strategies for the APTVs: holding and speed changing. The solution methodology proposed is based on time-space graphical techniques using multi-criteria decision analysis to minimize schedule changes as the primary objective, as well as to reduce travel time and active energy consumption. Two multi-objective models are developed for not-considered and considered vehicle capacity and then examined using a simulation framework. A case study from Auckland, New Zealand, is selected, which assumes that ordinary buses are replaced with APTVs. The results indicate that the strategy-based optimal schedule adjustments achieve a 100% elimination of schedule deviations compared with 33-minute and 13-minute deviations for the low-demand and high-demand scenarios of the ordinary PT service, respectively. The results of the simulated case study indicate that the incorporation of APTVs, along with prudent control, can result in a more attractive PT service.

Autonomous shuttle bus for public transportation: A review

1. Year: 2020
2. Journal: Energies
3. Authors: Iclodean, Calin and Cordos, Nicolae and Varga, Bogdan Ovidiu

> The rapid evolution of autonomous technology in the field of automotive and information technology (IT) has made it possible to implement autonomous vehicles (AVs) for public passenger transport. Although the shuttle bus transport capacities currently in use are low (maximum 15 people), the use of these transport units in large urban agglomerations is beneficial for society. The current paper is written to review the current AV implementation with respect to shuttle buses with its direct implications in their scientific evolution, with direct links to the legal and social aspects of public transportation all over the world. A critical aspect that is presented in the paper is the legal framework of autonomous driving, which is extremely uneven around the globe, with the direct impact of autonomous shuttle bus exploitation. As the legislation on AVs presents some shortcomings in the approval, registration, and public road implementation of these vehicles, many of the world's major cities have found ways to integrate them into testing programs, establishing the basis for future comprehensive legislative measures in this highly dynamic scientific domain. The current technological solutions adopted by several autonomous shuttle bus producers will be presented with an exhaustive overview of each major component. The aspects of the control algorithm, with its complicated layers of security and perturbance factors, will be explained in detail. Thus, in some countries/cities, autonomous shuttle buses have been implemented on less-traveled routes where they can travel at speeds up to 25 km/h without hindering the public's circulation, such as university campuses, industrial areas, airports, and sports bases. Some countries/cities use autonomous shuttle buses for pilot programs related to passenger transport, while others use them in postal transport and others for scientific purposes. In all of these situations, the first step in autonomous driving has been taken. The paper also makes an evaluation of the social factors that are a consequence of the mass introduction of autonomous driving as a means of public transportation. Autonomous shuttle buses are becoming a part of everyday life in big cities. Their acceptance as a strategic means of transport depends on their efficiency in daily services; through its efficiency, this means of transport will become a game-changer once its benefits become not only known but experienced by a large number of users.

Impact of electric bus charging on distribution substation and local grid in Warsaw

1. Year: 2020
2. Journal: Energies
3. Authors: Zagrajek, Krzysztof and Paska, J{'{o}}zef and K{\l}os, Mariusz and Pawlak, Karol and Marchel, Piotr and Bartecka, Magdalena and Michalski, {\L}ukasz and Terlikowski, Pawe{\l}

> Electric buses are increasingly appearing on the streets of cities around the world. Thus, it is necessary to consider the impact of their charging on the distribution system operation, especially near the charging point. This article presents the problems that may arise while new charging points are connected. Research was carried out on the existing charging point at Sparta{'{n}}ska Street in Warsaw, which allowed to obtain daily bus charging profiles and voltage curves. The authors then proposed an exemplary model of a bus terminus with the designed infrastructure for charging buses, based on the assumptions of the public transport operator in Warsaw. The comparison of these two solutions was made and based on it, a methodology of calculating daily demand for any terminus was prepared. In addition, no problems with the power quality were found during the research. This allows us to state that the introduction of electric buses into the fleet of passenger carriers will have a minor impact on the operation of the power system in Warsaw.

Joint design of multimodal transit networks and shared autonomous mobility fleets

1. Year: 2020
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Pinto, Helen K.R.F. and Hyland, Michael F. and Mahmassani, Hani S. and Verbas, I. {"{O}}mer

> Providing quality transit service to travelers in low-density areas, particularly travelers without personal vehicles, is a constant challenge for transit agencies. The advent of fully-autonomous vehicles (AVs) and their inclusion in mobility service fleets may allow transit agencies to offer better service and/or reduce their own capital and operational costs. This study focuses on the problem of allocating resources between transit patterns and operating (or subsidizing) shared-use AV mobility services (SAMSs) in a large metropolitan area. To address this question, a joint transit network redesign and SAMS fleet size determination problem (JTNR-SFSDP) is introduced, and a bi-level mathematical programming formulation and solution approach are presented. The upper-level problem modifies a transit network frequency setting problem (TNFSP) formulation via incorporating SAMS fleet size as a decision variable and allowing the removal of bus routes. The lower-level problem consists of a dynamic combined mode choice-traveler assignment problem (DCMC-TAP) formulation. The heuristic solution procedure involves solving the upper-level problem using a nonlinear programming solver and solving the lower-level problem using an iterative agent-based assignment-simulation approach. To illustrate the effectiveness of the modeling framework, this study uses traveler demand from Chicago along with the region's existing multimodal transit network. The computational results indicate significant traveler benefits, in terms of improved average traveler wait times, associated with optimizing the joint design of multimodal transit networks and SAMS fleets compared with the initial transit network design.

Joint optimization of scheduling and capacity for mixed traffic with autonomous and human-driven buses: A dynamic programming approach

1. Year: 2020
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Dai, Zhuang and Liu, Xiaoyue Cathy and Chen, Xi and Ma, Xiaolei

> It is a common practice for transit lines with fluctuating passenger demands to use demand-driven bus scheduling to reduce passenger waiting time and avoid bus overcrowding. However, current literature on the demand-driven bus scheduling generally assumes fixed bus capacity and exclusively optimizes bus dispatch headways. With the advent of connected and autonomous vehicle technology and the introduction of autonomous minibus/shuttle, the joint design of bus capacity and dispatch headway holds promises to further improving the system efficiency while reducing operating and passenger costs. This paper formulates this problem as an integer nonlinear programming model for transit systems operating with mixed human-driven and autonomous buses. In such mixed operating environment, the model simultaneously considers: (1) dynamic capacity design of autonomous bus, i.e., autonomous buses with varying capacity can be obtained by assembling and/or dissembling multiple autonomous minibuses; (2) trajectory control of autonomous bus, i.e., autonomous bus can dynamically adjust its running time as a function of its forward and backward headways; and (3) stop-level passenger boarding and alighting behavior. The objective of the model is designed to balance the trade-off between the operating costs of dispatching different types of bus and the costs of increased passenger waiting time due to inadequate bus dispatching. The model is solved using a dynamic programming approach. We show that the proposed model is effective in reducing passenger waiting time and total operating cost. Sensitivity analysis is further conducted to explore the impact of miscellaneous factors on optimal dispatching decisions, such as penetration rate of autonomous bus, bus running time variation, and passenger demand level.

Sustainable mobility

1. Year: 2020
2. Journal: Handbook of Urban Mobilities
3. Authors: N{\ae}ss, Petter

> Sustainable mobility must ensure ecological sustainability, satisfy basic needs and be socially just across and within generations. Three main strategies should be combined to obtain ecological sustainability: making each separate mode of transport more energy-efficient and environmentally friendly, promoting a shift to more environmentally friendly modes of transport, and reducing the movement of persons and goods. Social sustainability requires that ecologically sustainable mobility must be obtained while securing everyone accessibility to the facilities and people they need to visit in their daily life. Land use planning can play an important role in providing accessibility within ecologically sustainable mobility volumes.

Test-riding the driverless bus: Determinants of satisfaction and reuse intention in eight test-track locations

1. Year: 2020
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Rosell, Jordi and Allen, Jaime

> The introduction of shared autonomous vehicles (SAVs) presents a wide range of challenges and uncertainties regarding their general acceptability. Hence, it is essential that transit managers have a good understanding of passenger satisfaction and of their behavioural intentions after experiencing a driverless vehicle trip. To this end, 1,062 face-to-face surveys were conducted following driverless bus trials in eight Catalan (Spain) municipalities. Using a three-step SEM-MIMIC ordinal Probit approach, we seek to identify the heterogeneity in user perceptions and reuse intentions, a novelty in SAV

> literature. Specifically, we analyse the users' behavioural intention to repeat a journey without transit support personnel on the bus and when entirely alone, and how willing they are to substitute their regular bus service with a driverless one. Our results confirm that critical incidents affect user satisfaction concerning safety, the latter constituting one of the most critical factors impacting user reuse intention and overall satisfaction. The test-track scenario also affects reuse intention, with university campuses and parks recording better outcomes than city centres and pedestrianized zones. In contrast to outcomes reported for conventional bus systems, higher socioeconomic status is associated with higher levels of satisfaction with driverless vehicles and a stronger reuse intention. Female users are reluctant to ride on driverless buses alone; however, when they are not regular bus users, they express a reluctance to board SAV both without transit support personnel and alone. In high-income municipalities, we find a positive impact on reuse intention. Finally, a higher degree of satisfaction with the regular bus system is positively linked with a better perceived driverless bus experience. For implementation purposes, location, critical incidents, safety, regular bus user satisfaction, technology affinity, and the income level of the municipalities are all aspects that need to be factored-in when designing an adoption strategy.

Transitioning towards the deployment of line-based autonomous buses: Consequences for service frequency and vehicle capacity

1. Year: 2020
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Hatzenb{"{u}}hler, Jonas and Cats, Oded and Jenelius, Erik

> The deployment of autonomous buses (AB) is expected to have consequences for service design facilitated by its cost function structure. We study the impacts of AB deployment in line-based public transport (PT) systems. In particular, we examine the transition phase where AB is sequentially deployed, involving the selection of lines for which AB will be introduced. To this end, we develop a modeling framework using a dynamic public transportation assignment and operations simulation model that captures users' adaptive path choices. An analytical model is used to determine the initial solutions in terms of service frequency and vehicle capacity for the simulation framework. Due to their different cost function structures, the deployment of AB may be accompanied by changes in the service frequency and vehicle capacity settings and consequently also on passenger flow distribution across the network. Both the simultaneous and the sequential deployment of AB on multiple lines are investigated. Deployment solutions are assessed in terms of the both total operator and user cost. The decision variables are vehicle capacity per line, service frequency per line and vehicle technology per line - i.e. either manually driven or fully automated buses. The framework is applied to a case study in Kista, Stockholm. The study shows that AB service have the potential to attract passengers through improved service provision. A sensitivity analysis is carried out concerning the effects of different cost parameters and demand levels on the deployment of AB in fixed line operations.

Willingness to ride and perceptions of autonomous public transit

1. Year: 2020
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Kassens-Noor, Eva and Kotval-Karamchandani, Zeenat and Cai, Meng

> Autonomous vehicles (AVs) hold great promise to contribute to global sustainability by expanding access to mobility. The introduction of autonomous buses and shuttles could be a turning point for

> public mobility in the USA, but how autonomous public transit is perceived remains largely unknown. To fill this gap, this study analyzes the willingness to use autonomous buses and shuttles based on two surveys conducted in Michigan. These surveys were a phone-based random-sampling survey of the general public and an on-board intercept survey of public transit riders. We found that autonomous buses might increase willingness to use public transit. 15% of people, who occasionally ride or do not ride public transit, embrace the idea of using autonomous bus service, while fixed-route riders were more likely to accept AVs than demand-response transit riders. However, about half of the public transit riders were hesitant about riding in autonomous buses citing concerns over safety, no human, and distrust in technology. Willingness to ride was higher among younger males than it was for females, seniors, and people with mobility disabilities. In addition, our data suggests that riders' satisfaction with their drivers - be it skill, professionalism, or friendliness - had no impact on willingness to ride in AVs. As AVs become ready for deployment, policymakers and public transportation service providers should consider AV acceptance among vulnerable individuals to bring AV benefits to all.

A decision support framework for grid-aware electric bus charge scheduling

1. Year: 2021
2. Journal: 2021 IEEE Power and Energy Society Innovative Smart Grid Technologies Conference, ISGT 2021
3. Authors: Pettet, Geoffrey and Ghosal, Malini and Mahserejian, Shant and Davis, Sarah and Sridhar, Siddharth and Dubey, Abhishek and Kintner-Meyer, Michael

> While there are many advantages to electric publictransit vehicles, they also pose new challenges for fleet operators. One key challenge is defining a charge scheduling policy that minimizes operating costs and power grid disruptions while maintaining schedule adherence. An uncoordinated policy could result in buses running out of charge before completing their trip, while a grid agnostic policy might incur higher energy costs or cause adverse impact on the grid's distribution system. We present a grid aware decision theoretic framework for electric bus charge scheduling that accounts for energy price and grid load The framework co-simulates models for traffic (Simulation of Urban Mobility) and the electric grid (GridLAB_D), which are used by a decision theoretic planner to evaluate charging decisions with regard to their long-term effect on grid reliability and cost. We evaluated the framework on a simulation of Richland, WA's bus and grid network, and found that it could save over 100k per year on operating costs for the city compared togreedy methods.

A modular, adaptive, and autonomous transit system (MAATS): A in-motion transfer strategy and performance evaluation in urban grid transit networks

1. Year: 2021
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Wu, Jiaming and Kulcs{'{a}}r, Bal{'{a}}zs and Selpi and Qu, Xiaobo

> Dynamic traffic demand has been a longstanding challenge for the conventional transit system design and operation. The recent development of autonomous vehicles (AVs) makes it increasingly realistic to develop the next generation of transportation systems with the potential to improve operational performance and flexibility. In this study, we propose an innovative transit system with autonomous modular buses (AMBs) that is adaptive to dynamic traffic demands and not restricted to fixed routes and timetables. A unique transfer operation, termed as “in-motion transfer”, is introduced in this paper to transfer passengers between coupled modular buses in motion. A two-stage model is developed to facilitate in-motion transfer operations in optimally designing passenger transfer plans and AMB

> trajectories at intersections. In the proposed AMB system, all passengers can travel in the shortest path smoothly without having to actually alight and transfer between different bus lines. Numerical experiments demonstrate that the proposed transit system results in shorter travel time and a significantly reduced average number of transfers. While enjoying the above-mentioned benefits, the modular, adaptive, and autonomous transit system (MAATS) does not impose substantially higher energy consumption in comparison to the conventional bus system.

Analysis of electric moped scooter sharing in berlin: A technical, economic and environmental perspective

1. Year: 2021
2. Journal: World Electric Vehicle Journal
3. Authors: Wortmann, Chris and Syr{'{e}}, Anne Magdalene and Grahle, Alexander and G{"{o}}hlich, Dietmar

> Electric moped scooter sharing services have recently experienced strong growth rates, par-ticularly in Europe. Due to their compactness, environmental-friendliness and convenience, shared e-mopeds are suitable for helping to reduce the environmental impact of urban transport. However, its traffic-related, economic and environmental effects are merely represented in academic research. Therefore, this study investigates the ability of an e-moped sharing system to substitute passenger car trips, and the resulting economic and environmental effects. First, we model fleets of 2500, 10,000 and 50,000 shared e-mopeds in Berlin, based on a passenger car scenario generated by the multi-agent transport simulation framework MATSim. Afterwards, the total cost of ownership and a life cycle assessment are conducted. The results indicate that a substantial part of all passenger car trips in Berlin can be substituted. The larger the fleet, the more and longer trips are replaced. Simultaneously, the efficiency in terms of fleet utilization decreases. The scenario with 10,000 e-mopeds offers the lowest total distance-based costs for sharing operators, whereas a fleet consisting of 2500 vehicles exhibits the lowest environmental emissions per kilometer. Already with today's grid mix, the use of shared e-mopeds results in a significant reduction in environmental impact compared to conventional and battery-electric passenger cars.

Competition between shared autonomous vehicles and public transit: A case study in Singapore

1. Year: 2021
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Mo, Baichuan and Cao, Zhejing and Zhang, Hongmou and Shen, Yu and Zhao, Jinhua

> Emerging autonomous vehicles (AV) can either supplement the public transportation (PT) system or compete with it. This study examines the competitive perspective where both AV and PT operators are profit-oriented with dynamic adjustable supply strategies under five regulatory structures regarding whether the AV operator is allowed to change the fleet size and whether the PT operator is allowed to adjust headway. Four out of the five scenarios are constrained competition while the other one focuses on unconstrained competition to find the Nash Equilibrium. We evaluate the competition process as well as the system performance from the standpoints of four stakeholders—the AV operator, the PT operator, passengers, and the transport authority. We also examine the impact of PT subsidies on the competition results including both demand-based and supply-based subsidies. A heuristic algorithm is proposed to update supply strategies for AV and PT based on the operators' historical actions and

> profits. An agent-based simulation model is implemented in the first-mile scenario in Tampines, Singapore. We find that the competition can result in higher profits and higher system efficiency for both operators compared to the status quo. After the supply updates, the PT services are spatially concentrated to shorter routes feeding directly to the subway station and temporally concentrated to peak hours. On average, the competition reduces the travel time of passengers but increases their travel costs. Nonetheless, the generalized travel cost is reduced when incorporating the value of time. With respect to the system efficiency, the bus supply adjustment increases the average vehicle load and reduces the total vehicle kilometers traveled measured by the passenger car equivalent (PCE), while the AV supply adjustment does the opposite. The results suggest that PT should be allowed to optimize its supply strategies under specific operation goals and constraints, and AV operations should be regulated to reduce their system impacts, including potentially limiting the number of licenses, operation time, and service areas, which makes AV operate in a manner more complementary to the PT system. Providing subsidies to PT results in higher PT supply, profit, and market share, lower AV supply, profit, and market share, and increased passenger's generalized cost and total system PCE.

Design and operation of feeder systems in the era of automated and electric buses

1. Year: 2021
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Badia, Hugo and Jenelius, Erik

> This paper evaluates the impact of vehicle automation and electrification on the applicability of fixed routes and door-to-door services to supply a feeder transit solution in suburban areas. These technologies will modify the current cost structure of the bus system depending on how mature they are, reducing operating costs and increasing capital costs. By means of a continuum approximation model, we evaluate the performance for users and agency of the two feeder strategies in different scenarios of technological development. The results show that automation has the main impact on the applicability between the two feeder alternatives while the effects of electrification are considerably smaller. The future applicability of door-to-door trips reaches wider ranges, although this change is especially significant under some circumstances of technology, service area and users. The expansion of this range is relevant in case the automated bus is mature enough (high reduction of operating cost and low vehicle acquisition price), the areas are small, the trips are short and the value of time is high. However, the results reveal that fixed routes will remain a competitive feeder solution in a wide range of scenarios. We identify that the demand density threshold grows sharply in front of any reduction of agency costs once its value is around 200–300 pax/km2-h. Therefore, flexible services will gain applicability especially in environments that allow reaching this threshold.

Improving flex-route transit services with modular autonomous vehicles

1. Year: 2021
2. Journal: Transportation Research Part E: Logistics and Transportation Review
3. Authors: Liu, Xiaohan and Qu, Xiaobo and Ma, Xiaolei

> With the advent of modular autonomous vehicles (MAVs), this paper presents a novel operational design for flex-route transit services to reduce operation costs of vehicles and improve the service quality of customers. The regime allows the simultaneous dispatch of a certain amount of MAVs from a bus terminal at a departure time. Each MAV is allowed to visit customers freely outside of checkpoints. Self-adaptive capacity and flexible service mode adapt time- and space-dependent demand

> characteristics. The presented operational design is formulated as a mixed-integer linear program that is NP-hard. A two-stage solution framework is developed to decompose the proposed mathematical programming cautiously. In the first stage, customized dynamic programming with valid cuts is designed to solve a bus scheduling problem efficiently. In the second stage, an effective and fast heuristic is proposed to solve a variant of the dial-a-ride problem and satisfy the technical requirements for developing on-line applications. Numerical examples and a case study show the effectiveness of the proposed design by comparing the flex-route transit services using traditional vehicles.

Location and capacity decisions for electric bus charging stations considering waiting times

1. Year: 2021
2. Journal: Transportation Research Part D: Transport and Environment
3. Authors: Uslu, Tugce and Kaya, Onur

> This research proposes a mixed integer-linear mathematical model for location and capacity decisions of electric bus charging stations in order to ensure the connectivity of the road network throughout a certain region. The routes followed by electric buses in a country, demand in each route and driving ranges of electric buses are considered so as to determine the locations and capacities of charging stations under limited waiting time constraints. We implement the model on a case study for intercity bus networks in Turkey and use the actual data of coach companies. The results provide optimal locations and capacities of charging stations with minimum cost. Moreover, sensitivity analysis is performed to analyze the effects of different parameters on the results. It is observed that driving ranges have the highest importance in the efficient use of electric buses, and charging durations, number of trips and service rates significantly affect capacities of stations.

Resilient Restoration of Distribution Systems in Coordination with Electric Bus Scheduling

1. Year: 2021
2. Journal: IEEE Transactions on Smart Grid
3. Authors: Li, Boda and Chen, Ying and Wei, Wei and Huang, Shaowei and Mei, Shengwei

> Electric buses (EBs) possess large-capacity batteries and are dispatched by a central operator, exhibiting great potential to enhance the resilience of distribution systems (DSs) against meteorological disasters. This paper proposes an optimization model for joint post-disaster DS restoration, considering coordinated dispatching with EBs. By assuming that the DS can rent some EBs from the bus company, an EB scheduling problem with adjustable timetables is established. Idle buses are placed at designated areas and feed power back to the grid via charging piles or charging stations in case of need. The schedule of the remaining buses should meet the passenger transport demand, which is smaller than usual because of bad weather. The objective is to maximize the total benefits and minimize the EB rental cost of the grid company. Techniques in integer algebra are used to reformulate the proposed restoration problem with bus scheduling constraints as a mixed-integer linear program, which can be processed by off-the-shelf solvers. The proposed method is tested on a modified 15-bus system and IEEE 123-bus system. The results demonstrate that the resilience of the system is enhanced, and the benefits of the grid company increase significantly, because of the flexibility brought by EBs.

Routing and Scheduling of Electric Buses for Resilient Restoration of Distribution System

1. Year: 2021

2. Journal: IEEE Transactions on Transportation Electrification
3. Authors: Li, Boda and Chen, Ying and Wei, Wei and Huang, Shaowei and Xiong, Yufeng and Mei, Shengwei and Hou, Yunhe

> Electric buses (EBs) have been widely adopted in public transit. EBs can feed power back to the distribution system (DS) at a charging station and serve as temporary mobile power sources (MPSs), such as hurricanes. Thus, they have great potential to enhance grid resilience against meteorological disasters. This article proposes a DS restoration method for enhancing resilience considering the routing and scheduling of a group of EBs. To maintain the function of EBs in public transit, we establish an EB scheduling problem (EBSP) with predetermined optional service trips. The schedule must meet a certain public transit demand, and the not-in-service EBs can transfer power among charging stations, unleashing their abilities as MPSs. The proposed model considers the en-route energy consumption of EBs, and the restoration process aims to minimize the losses of loads over time and the energy usage of EBs for supporting the grid. The problem is finally cast as a mixed-integer linear program (MILP), which can be processed by off-the-shelf solvers. The proposed model is tested on two systems with dozens of EBs. The results validate our work's effectiveness and demonstrate the potential of EBs in enhancing the resilience of DSs.

The depot and charging facility location problem for electrifying urban bus services

1. Year: 2021
2. Journal: Transportation Research Part D: Transport and Environment
3. Authors: Hsu, Yu Ting and Yan, Shangyao and Huang, Powei

> The transition from diesel-consuming buses to electric ones entails the problem of determining the locations of bus depots, charging and maintenance stations, which can directly affect the operating cost and efficiency of a bus system. The problem also involves practical concerns, including the selection of fleet size (of electric buses), land acquisition, bus allocation, and the associated deadhead mileage. This study develops an optimization model to systematically locate depots and relevant facilities for deploying mixed types of vehicles. Further, a decomposition-based heuristic algorithm is proposed to enhance computational efficiency. A case study is performed using the data of a bus operator in Taiwan. Sensitivity and scenario analyses are conducted, evaluating major cost components and identifying the factors that affect the trade-offs between them. The proposed methodology enables bus operators/planners to closely and holistically examine their decisions during the transition toward electric bus systems.

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Urban mobility and public transport: future perspectives and review

1. Year: 2021
2. Journal: International Journal of Urban Sciences
3. Authors: Ceder, Avishai (Avi)

> The purpose of this work is to review urban transportation likely to be offered in the future. Trip-making behaviour has already changed considerably as lifestyles change and they will continue to change in the future. This work reflects and places emphasis on profound thinking about the possibilities, rather than predicting them. Thoughts about possibilities for the future draw upon imagination, perceived and justified feasibility, and lessons gained from the past. This work attempts to capture the possibilities, logistics and travel modes of future urban transportation. A visionary, feasibility-related approach grounded in a realist perspective is proposed, only conceptually, to explore plausible visions for the future. In addition, this work shows the inefficiency of using private cars (PCs) and argues that in the development of autonomous and electric vehicles, PCs cannot provide a solution competitive with the potential that urban transportation systems have for the future. Hence, the solutions for the future must be based on public transport (PT) modes of travel, regardless of whether they are metro, bus, light rail, tram, ridesharing services, an ordinary taxi, personal rapid transit, or any other PT-based future mode. The key principal of operation for the mobility of a smart city will be the ability to optimize the connectivity of movement in order to approach a seamless move, while endowing the phrase door-to-door travel with new meaning. Finally, it would be remiss not to mention the unforeseeable implications of the Covid-19 pandemic for future mobility, more controllable by automation of non-privately owned vehicle, and with the prospect of people demonstrating a greater inclination towards changing their habits, behaviour, and thinking paradigms.

Vehicle and reliable driver scheduling for public bus transportation systems

1. Year: 2021
2. Journal: Transportation Research Part B: Methodological
3. Authors: Andrade-Michel, Alejandro and R{'{i}}os-Sol{'{i}}s, Yasm{'{i}}n A. and Boyer, Vincent

> We propose the bus vehicle and reliable driver scheduling problem that is an integrated approach for the vehicle and the crew scheduling problems considering driver's reliability information to reduce the number of no-covered trips along the day and thus improve the user's satisfaction. An exact constraint programming model is proposed and compared with a variable neighborhood search that incorporates the driver's reliability and the trip's importance. The obtained trip-vehicle-driver assignments are evaluated on many scenarios with a Monte Carlo method to simulate the driver's absenteeism. Experimental results on randomly generated instances based on a real case study show our methodologies' efficiency and the enormous gains in covered trips when the drivers' reliability is considered.

A review of electric bus vehicles research topics – Methods and trends

1. Year: 2022
2. Journal: Renewable and Sustainable Energy Reviews
3. Authors: Manzolli, J{^{o}}natas Augusto and Trov{~{a}}o, Jo{~{a}}o Pedro and Antunes, Carlos Henggeler

> The transportation sector accounts for a significant share of greenhouse gas emissions. Hence, the electrification of this sector is a crucial contributor to the mitigation of global warming. Recent studies suggest that electric vehicles will be economically paired with internal combustion engine vehicles in the near future. However, relying on private vehicle decarbonization only cannot deliver comprehensive space management efficiency solutions in urban environments. Therefore, it is essential to invest in the technological development and deployment of electric buses for public transportation, directly enhancing the quality of life in large cities. From this perspective, this review examines a wide range of scientific literature on electric bus research using science mapping methods and content analysis to support critical thinking unveiling the main research streams, methods, and gaps of the field. The analysis indicates that future research on electric buses will be mainly devoted to sustainability (encompassing economic, environmental and quality of service dimensions), energy management strategies, and fleet operation.

Collaborative EV Routing and Charging Scheduling With Power Distribution and Traffic Networks Interaction

1. Year: 2022
2. Journal: IEEE Transactions on Power Systems
3. Authors: Liu, Jiayan and Lin, Gang and Huang, Sunhua and Zhou, Yang and Rehtanz, Christian and Li, Yong

> The increasing of electric vehicles (EVs) alleviates the faced environmental problems but brings challenges to the optimal operation of transportation network (TN) and distribution network (DN). However, the most of existing research works consider EV charging station assignment and navigation services in the TN separately from charging station power scheduling services in the DN. To overcome this research gap, this paper proposes a collaborative optimal routing and scheduling (CORS) method, providing optimal route to charging stations and designing optimized charging scheduling schemes for each EV. In the order of reporting, whenever an EV reports its charging demand, a CORS optimization model is built and solved so that a specific charging scheme is designed for that EV. Then, the TN and DN status is updated to guide the subsequent EVs operating. The proposed CORS integrates the real-time state of the TN and DN, and effects positive benefits in helping EVs to avoid traffic congestion, improving the utilization level of charging facilities and enhancing charging economy. The combined distributed biased min consensus algorithm and generalized benders decomposition algorithm are adopted to solve the complex nonlinear optimization problem. Through comparing with the existing methods, better effectiveness is verified by simulation results.

Designing transit-oriented multi-modal transportation systems considering travelers' choices

1. Year: 2022
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wang, Yineng and Lin, Xi and He, Fang and Li, Meng

> One goal of future transit-oriented transportation systems is to promote door-to-door mobility for travelers by integrating different public transportation modes into a whole. We propose a

> mathematical design framework for such a transit-oriented multi-modal transportation system from a societal aspect considering three categories of public transportation modes, i.e., general on-demand modes, local on-demand modes, and fixed-schedule modes. A system-state equilibrium is brought up to describe travelers' rational travel choices and their reverse effects on agency service levels using the continuous approximation method, and a centralized system designer then manages to achieve a system-beneficial outcome with the minimum cost. To solve the design problem, we prove that the transportation system reaches a unique equilibrium when decision variables are given. By this discovery, we construct a global search framework based on the DIRECT algorithm to solve the optimal design. In analyzing the problem property, we rigorously prove that in the designed systems, the bus service as a fixed-schedule mode is absent from the design scheme under the cases with sufficiently low demands, and the design problem thus reduces to a one-dimensional line search. The ride-hailing service as a general on-demand mode is similarly proved to be excluded when the demand is sufficiently high. In this context, the approximate design parameters of the bus service and the total system cost are developed analytically. The local on-demand mode, bike-sharing service, as an option of bus feeders, is proved to be efficient under a realistic setting. Extensive numerical examples provide evidence verifying the preceding analyses and indicating the behavior of travelers and agencies. Further sensitivity tests show that the subway is favorable for intensive demands and autonomous vehicles may promote the ride-hailing industry. For completeness, an immediate application of the proposed framework in generalized cases validates the model reliability.

Electric Bus Charging Scheduling for a Single Public Transport Route Considering Nonlinear Charging Profile and Battery Degradation Effect

1. Year: 2022
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zhou, Yu and Meng, Qiang and Ong, Ghim Ping

> This study deals with a fundamental electric bus charging scheduling (EBCS) problem for a single public transport route by considering the nonlinear electric bus (EB) charging profile and battery degradation effect under the partial charging policy, which allows EBs to be charged any length of time and make good use of dwell times between consecutive trips. Given a group of trip tasks for an EB fleet and charger type, the problem is to minimize the total cost for a public transport operator of providing peak-hour bus services for a focal single public transport route by simultaneously determining the EB-to-trip assignment and EB charging schedule with charger type choice subject to the necessary EB operational constraints. We first build a mixed-integer nonlinear and nonconvex programming (MINL&NCP) model for the EBCS problem. To effectively solve the MINL&NCP model to global optimality, we subsequently develop two mixed-integer linear programming (MILP) models by means of linearization and approximation techniques. To accelerate the solution efficiency, we further create three families of valid inequalities depending on the unique features of the problem. A real case study based on the No.171 bus route in Singapore is conducted to demonstrate the performance of the developed models. Extensive numerical experiments are carried out to seek valuable managerial insights for public transport operators.

Electric bus planning & scheduling: A review of related problems and methodologies

1. Year: 2022
2. Journal: European Journal of Operational Research
3. Authors: Perumal, Shyam S.G. and Lusby, Richard M. and Larsen, Jesper

> Electrification of bus fleets in most cities is expected to rise due to its significant environmental benefits. However, electric buses have limited driving range and long recharging times. Additionally, electric buses require special charging infrastructure, which overall makes them less flexible than conventional diesel buses. Due to the limitations of the electric bus technologies, further adjustments have to be made to the current bus transport planning problems. The scheduling of electric vehicles is recognized as a fast-growing area of research. In this paper, we review 43 articles related to the electric bus technologies and give an overview of the different problems in the electric bus planning process (strategic, tactical and operational). The different problems are: 1) investment of electric bus fleet and charging infrastructure, 2) placement of charging infrastructure, 3) the electric vehicle scheduling problem (E-VSP) and 4) the charging scheduling problem. Given a set of timetabled trips and recharging stations, the E-VSP is concerned with finding a vehicle schedule that covers the trips and satisfies the driving range and recharging requirements of electric buses while minimizing operational cost. A detailed literature review of the constraints associated with the E-VSP and the solution approaches proposed to solve it is given. Rescheduling aspects or considerations of robustness for scheduling of electric vehicles is identified as a future area of research. Furthermore, integrated electric bus planning is considered as a crucial area of research and integrated approaches could further improve the efficiency of electric bus transport systems.

Electric Bus Scheduling and Timetabling, Fast Charging Infrastructure Planning, and Their Impact on the Grid: A Review

1. Year: 2022
2. Journal: Energies
3. Authors: Alamatsaz, Kayhan and Hussain, Sadam and Lai, Chunyan and Eicker, Ursula

> Transit agencies are increasingly embracing electric buses (EB) as an energy-efficient and emission-free alternative to the conventional bus fleets. They are rapidly replacing conventional buses with electric ones. As a result, emerging challenges of electrifying public transportation bus networks in cities should be addressed. Introducing electric buses to the bus transit system would affect the public transit operation planning steps. The steps are network design, timetabling, bus scheduling, and crew scheduling. Regarding the functional and operational differences between conventional buses and electric buses, such stages should be changed and optimized to enhance the level of service for the users while reducing operating costs for service providers. Many mathematical optimization models have been developed for conventional buses. However, such models would not fit the electric buses due to EBs' limited traveling range and long charging time. Therefore, new mathematical models should be developed to consider the unique features of electric buses. We present a comprehensive literature review to critically review and classify the work done on these topics. This paper compares the studies that have been done in this field and highlight the missing links and gaps in the considered papers, and the potential future studies that could be done. The considered papers cover the integration of timetabling and vehicle scheduling, recharging scheduling planning, and fast charging infrastructure location planning and its impacts on the grid. The main goal of this research is to highlight the research gaps and potential directions for future studies in this domain to encourage more realistic and applicable models and solution approaches for fully electric bus transit systems.

Joint optimization of timetabling, vehicle scheduling, and ride-matching in a flexible multi-type shuttle bus system

1. Year: 2022

2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Wu, Mian and Yu, Chunhui and Ma, Wanjing and An, Kun and Zhong, Zhihua

> Shuttle bus services play a vital role in public transit systems. However, conventional shuttle bus systems use the same type of buses and fixed departure timetables. They fail to meet the time-varying travel demand and do not consider the diversified characteristics of transit passengers. With the advent of the information era, communication among passengers, buses, and dispatching centers has become much easier. Accordingly, demand-responsive bus dispatching methods are expected to increase the flexibility of operation schemes to improve the performance of shuttle bus systems. To this end, this study proposes a mixed-integer linear programming model to incorporate ride-matching and shuttle bus dispatching in one framework. The bus trip schedules (including the number of used bus trips of different types, departure times, dwelling stops with dwelling times, and recommended travel speeds between adjacent stops of each trip) and passenger-to-vehicle matching schemes are optimized. The commonly used stop-skipping tactic, speed adjustment, and bus holding strategies are introduced to improve the flexibility and operational efficiency of shuttle bus systems. The objective is to minimize the weighted total passenger waiting times, passenger in-vehicle times, and operating costs. A modified Lagrangian relaxation algorithm is designed to improve computational efficiency for large-scale problems. A rolling horizon scheme is designed to implement the algorithm dynamically. It updates the dispatching scheme horizon by horizon according to newly collected requests, which can also improve the algorithm performance by reducing the problem scale. Numerical results show that the proposed flexible multi-type shuttle bus system outperforms a multi-type bus timetabling algorithm in all the considered cases, and it outperforms an on-demand ride-sharing algorithm in 80% of the cases.

Optimal deployment of autonomous buses into a transit service network

1. Year: 2022
2. Journal: Transportation Research Part E: Logistics and Transportation Review
3. Authors: Tian, Qingyun and Wang, David Z.W. and Lin, Yun Hui

> Autonomous vehicles empowered by emerging automation technologies are highly anticipated to be introduced into public transit service operations in the future mobility system. Considering the low acceptance rate of the new service with autonomous buses when it is initially put into practice, it is not ideal to make a “one-off” deployment to replace all the service lines with autonomous bus services. Rather, the service operator is to determine an optimal plan for the deployment of autonomous buses onto different service lines in multiple stages. This paper proposes a multi-stage mathematical modeling framework to optimize the deployment strategy in which conventional buses are sequentially replaced by autonomous buses. More specifically, the model decides when (at which planning stage) and where (on which service line in the network) the deployment of autonomous buses should be conducted. Passengers' acceptance attitudes towards autonomous buses are explicitly considered in their transit routing choices. To forecast the evolution of the passengers' adoption rate of the autonomous bus service, a diffusion model is applied. The proposed multi-stage planning model framework, which is indeed a mixed-integer nonlinear program, is to determine the optimal deployment strategy that minimizes the total travel cost during the planning horizon. A two-phase solution method that combines a searching algorithm and a double projection method is proposed to solve the model. Finally, numerical studies are conducted to test the validity of the modeling framework and solution method. The impacts of passengers' adoption rate and other parameters on the deployment strategy are illustrated.

Optimization of service frequency and vehicle size for automated bus systems with crowding externalities and travel time stochasticity

1. Year: 2022
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Sadrani, Mohammad and Tirachini, Alejandro and Antoniou, Constantinos

Public transport is considered as one of the most suitable candidates to benefit from autonomous driving technologies. In this research, we develop a mathematical modeling framework to optimize service frequency and vehicle size for automated bus systems, while accounting for both user and operator costs. We explicitly consider travel time stochasticity, time-dependent passenger flows, vehicle capacity limitations (extra waiting time due to denied boarding), and in-vehicle discomfort externalities for both sitting and standing passengers at a microscopic level. We attempt to provide a thorough assessment of the service and cost implications of the deployment of automated buses. Hence, a broad range of experiments are simulated by combining different deployment cases: (i) vehicle technology (human-driven or automated vehicles), (ii) travel time assumptions (deterministic or stochastic travel times), and (iii) crowding externalities (considering or ignoring in-vehicle crowding costs). The model applicability is assessed on two real-world bus corridors in Regensburg (Germany) and Santiago (Chile). Results show that, with crowding externalities, optimal vehicle size is increased at a similar rate for both human-driven and automated bus services, whereas optimal service frequency is increased at a higher rate for automated buses. Thus, under optimal levels of supply, automated vehicles are operated with lower occupancy levels than human-driven vehicles, increasing the quality of service. Besides, the deployment of automated bus systems can significantly alleviate or eliminate denied boardings. The effects of automation on travel time volatility and dwell time regularity are studied. The consideration of stochastic travel times increases optimal frequencies at a higher rate for automated services relative to human-driven vehicles. Interestingly, we find that even though the operator benefits from automation are more pronounced in high-income countries (due to a greater potential for human driving cost savings), the final outcome is counterbalanced by the actual public transport demand level, because large user cost savings from automation are reachable in crowded routes even in situations in which labor costs are lower (as in developing countries).

Optimization of service frequency and vehicle size for automated bus systems with crowding externalities and travel time stochasticity

1. Year: 2022
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Public transport is considered as one of the most suitable candidates to benefit from autonomous driving technologies. In this research, we develop a mathematical modeling framework to optimize service frequency and vehicle size for automated bus systems, while accounting for both user and operator costs. We explicitly consider travel time stochasticity, time-dependent passenger flows, vehicle capacity limitations (extra waiting time due to denied boarding), and in-vehicle discomfort externalities for both sitting and standing passengers at a microscopic level. We attempt to provide a thorough assessment of the service and cost implications of the deployment of automated buses. Hence, a broad range of experiments are simulated by combining different deployment cases: (i) vehicle technology (human-driven or automated vehicles), (ii) travel time assumptions (deterministic or stochastic travel times), and (iii) crowding externalities (considering or ignoring in-vehicle crowding

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Subline frequency setting for autonomous minibusses under demand uncertainty

1. Year: 2022
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Gkiotsalitis, K. and Schmidt, M. and van der Hurk, E.

> Over the last years, there have been initiated several pilots with autonomous minibusses. Unlike regular bus services, autonomous minibusses serve a limited number of stops and have more flexible schedules since they do not require bus drivers. This allows the operation of a line through a flexible combination of sublines, where a subline serves a subset of consecutive stops in the same order as the original line. This paper studies the subline frequency setting (SFS) problem under uncertain passenger demand. We present a frequency setting model that assigns autonomous minibusses to sublines in order to exploit the available resources as much as possible and minimize the operational and passenger waiting time costs. Passenger waiting time costs may depend on the combination of several lines whose frequencies cannot be perfectly aligned for each passenger journey. We present a new estimation of the expected waiting time for passengers to improve the accuracy of the passenger waiting time costs in the case of sublines. Our SFS model is originally formulated as a MINLP and reformulated as a MILP that can be solved to global optimality. Further, we explicitly consider the uncertainty of passenger demand in the optimization process by formulating a stochastic optimization model. The performances of our stochastic and deterministic models that assign minibusses to sublines are tested under various passenger demand scenarios in the 14-stop autonomous minibus line in Eberbach, Germany and a fictional bus line with 20 bus stops. Results show potential improvements in operational costs in the range of 10%–40% depending on the passenger demand profile.

Application of modular vehicle technology to mitigate bus bunching

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Khan, Zaid Saeed and He, Weili and Men{'{e}}ndez, M{'{o}}nica

> The stochastic nature of public transport systems leads to headway variability and bus bunching, causing both operator and passenger cost to increase significantly. Traditional strategies to counter bus bunching, including bus-holding, stop-skipping, and bus substitution/insertion, suffer from trade-offs and shortcomings. Autonomous modular vehicle (AMV) technology provides an additional level of

> flexibility in bus dispatching and operations, which can offer significant benefits in mitigating bus bunching compared to strategies available with conventional buses. This paper introduces a novel alternative to stop-skipping by leveraging the new capabilities offered by AMVs (in particular, en-route coupling and decoupling of modular units). We develop a simple bus-splitting strategy that directs a modular bus to decouple into individual units when it experiences a headway longer than a given threshold. We then use a macroscopic simulation to present a proof-of-concept evaluation of the proposed modular strategy compared to a benchmark traditional stop-skipping strategy and the base (no control) case. We find that the proposed strategy outperforms the benchmark in decreasing each of the three travel time components: waiting time, in-vehicle time, and walking time (which it eliminates completely). It therefore reduces the overhead of bus bunching and thus the travel cost by more than twice as much as the benchmark for busy bus lines. Simultaneously, it also reduces headway variability to a comparable degree. Furthermore, we analyze different control thresholds for applying the proposed strategy, and show that it is most effective when applied proactively, i.e. with the control action being triggered even by small headway deviations.

Exploring the profitability of using electric bus fleets for transport and power grid services

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Fei, Fan and Sun, Wenzhe and Iacobucci, Riccardo and Schm{"{o}}cker, Jan Dirk

> Electric buses (E-buses) are increasingly replacing internal combustion powered bus fleets. They can further function as distributed energy storage units. We investigate the feasibility of the novel “Bus-to-Grid” (B2G) or “E-Buses as Power Storage” (EBaPS) concept, which allows battery E-buses to provide transportation as well as power-grid services. By aggregating the electrified bus fleets into Virtual Power Plants and discharging the energy to the grid, a bus operator can provide grid services and open up a secondary revenue source in addition to fareboxes. We discuss two contracts the bus operator can arrange with the grid. The first one is “Sale by Market Price (SbMP)”, presuming that the buses can discharge and sell the energy at real-time market prices. The second one is “Frequency Control Reserve (FCR)”, in which the buses discharge on immediate requests of the grid. We formulate the two contracts and their associated fleet allocation problems as two non-linear optimization problems maximizing the operator's profit. Optimal bus charging, discharging, and dispatching plans are solved on an aggregate level for strategic planning, allowing scalability to large fleet sizes. The profitability of the contracts is illustrated based on the schedule and demand of a real bus line and observed time-of-day dependent price variations of the energy market.

Fixed routing or demand-responsive? Agent-based modelling of autonomous first and last mile services in light-rail systems

1. Year: 2023
2. Journal: Transportation Research Part A: Policy and Practice
3. Authors: Rich, Jeppe and Seshadri, Ravi and Jomeh, Ali Jamal and Clausen, Sofus Rasmus

> This paper examines the potential of autonomous vehicle (AV) technology for enhancing first and last mile services for a light-rail station. We use an event- and agent-based simulation model to compare the performance of fixed and demand-responsive routing services. The routing of on-demand services is based on a matching algorithm in which incoming passenger requests are prioritized and assigned to vehicles under capacity constraints. Our findings indicate that, for a high-frequency light-rail feeder

> system, fixed routing is the preferred option, even with the assumed reduction in operational costs due to driver-less operations. However, we also observe that demand-responsive services can be as effective as fixed routing in off-peak hours, provided the heuristics for matching passengers to vehicles are effective. This implies that a combination of the two services could be beneficial in certain contexts. In addition, our results demonstrate that urban sprawl has an impact on the performance of the system, with the demand-responsive services becoming relatively better when urban sprawl increases, while the fixed routing remains superior across most key-performance indicators. To assess the performance of the different services, we employ cost–benefit analysis.

Generalized User Equilibrium for Coordination of Coupled Power-Transportation Network

1. Year: 2023
2. Journal: IEEE Transactions on Smart Grid
3. Authors: Shao, Chengcheng and Li, Ke and Qian, Tao and Shahidehpour, Mohammad and Wang, Xifan

> The increasing proliferation of electric vehicles (EVs) tightens the interaction between urban power distribution network (PDN) and transportation network (TN). This paper proposes the generalized user equilibrium (GUE) method for the coupled power-transportation network (CPTN) operation. First, the GUE concept is proposed to describe the steady traffic flow distribution as an extension of user equilibrium (UE), which could no longer exist due to the constraints placed by PDN operation on TN. Second, the GUE-based coordination model is established for CPTN with PDN generation scheduled and TN traffic assigned simultaneously. Finally, a decomposition method is developed to solve the model efficiently, which is converted into a master problem and a series of feasible/optimal path generation sub-problems for individual origin-destination (O-D) pairs. The case studies on a real-world network have verified the effectiveness of the proposed model and method. The results demonstrate the necessity of GUE and its potential in improving the CPTN operation.

Integrated electric bus timetabling and scheduling problem

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Xu, Xiaoming and Yu, Yanhong and Long, Jiancheng

> Vehicle timetabling and scheduling in a public transit system are usually performed separately, with the output of timetabling serving as the input of scheduling. An obvious drawback of this sequential planning method is that the trade-off between bus timetables and vehicle schedules may be neglected when determining solutions, which in turn results in that the obtained solutions may be inferior to those produced using an integrated framework. For example, a well-planned timetable may result in a schedule that requires a large vehicle fleet size with more operational cost, while a well-planned schedule may reduce the quality of a bus timetable by limiting the use of vehicles. In this paper, we introduce a time-space network-based framework for integrating electric bus timetabling and scheduling, with minimum and maximum headway times, depot requirements, deadheading and vehicle battery capacities considerations. The underlying time-space network is constructed with well-designed inventory arcs that represent multiple operations a bus may execute, thus decreasing the network size. Using the constructed network, we formulate the considered problem with a multi-commodity network flow model and develop a Lagrangian relaxation heuristic that consists of three phases, including generating relaxed solutions, making relaxed solutions feasible, and improving feasible solutions, to solve the integrated model. Tests on a set of instances confirm that the proposed

> integrated solution method can efficiently produce bus timetables and schedules with valid bounds, indicate that the integrated method can produce better solutions where the profit is increased by 5.29%–20.28%, and show how the headway times, service trip profit and operating cost settings affect the solution.

Integrated optimization of electric bus scheduling and charging planning incorporating flexible charging and timetable shifting strategies

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Duan, Mengyuan and Liao, Feixiong and Qi, Geqi and Guan, Wei

> In a battery electric bus (BEB) network, buses are scheduled to perform timetabled trips while satisfying time, energy consumption, charging, and operational constraints. Increasing research efforts have been dedicated to the integrated optimization of multiple planning tasks to reduce system costs. At a high integration level, this study determines the BEB scheduling and charging planning with flexible charging and timetable shifting strategies. We first formulate an integrated arc-based model to minimize the total costs considering the power grid pressure cost and subsequently reformulate it into a two-stage model, for which we develop an effective solution method. The first stage minimizes the total operational costs including the fleet, charging, and battery degradation costs based on the column generation technique, and the second stage minimizes the peak power demand through two timetable shifting strategies. It is found through numerical experiments that the proposed integrated optimization model and solution method can achieve significant improvement in the utilization rate and reductions in the fleet size, operational costs, and peak power demand compared to the two baseline models.

Integrated optimization of timetable, bus formation, and vehicle scheduling in autonomous modular public transport systems

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Liu, Zhengke and {Homem de Almeida Correia}, Gon{\c{c}}alo and Ma, Zhenliang and Li, Shen and Ma, Xiaolei

> This paper presents a joint optimization of the timetable, bus formation, and vehicle scheduling in a flexible public transport (PT) system that utilizes autonomous modular vehicles (AMVs). In this system, AMVs have the capability to detach or join with each other at intermediate stops along the route to dynamically adjust the bus formation (capacity). To increase vehicle utilization, a flexible scheduling strategy is proposed that allows AMVs to detach from one modular bus and join another modular bus in either direction of a bidirectional line. In particular, the penalty cost for each detachment or joining operation, as well as the limited number of available AMVs is explicitly considered. We formulate a unified model for the integrated optimization of the modular bus service (timetable and bus formation) and vehicle scheduling by introducing two types of decision variables. The objective is to minimize overall system costs, including passenger waiting time cost, operational costs, and detachment/joining penalty costs. The two types of decision variables are coupled by a vehicle resource consistency constraint, ensuring the conformity of the modular bus service and vehicle scheduling decisions. To tackle the complexity of our model, the Alternating Direction Method of Multipliers (ADMM) is employed to decompose it into two subproblems, which can be efficiently solved using a customized

> forward dynamic programming algorithm and a commercial solver. The model is validated using illustrative examples and a real-world instance from the Beijing Public Transport system, and it is compared with two benchmark models. Our results demonstrate the efficiency of the ADMM-based solution framework for solving the integrated optimization model. Furthermore, our findings indicate that the use of AMVs in PT systems can lead to reduced overall system costs and increased vehicle utilization.

Integrated solution for electric bus timetabling and vehicle scheduling combined with choices of charging locations

1. Year: 2023
2. Journal: Journal of Public Transportation
3. Authors: Quttineh, Nils Hassan and H{"{a}}ll, Carl H. and Ekstr{"{o}}m, Joakim and Ceder, Avishai (Avi)

> This paper presents a novel mathematical model, integrating timetabling and vehicle scheduling problems for electric buses. The objective is to minimize the number of buses while satisfying constraints concerning routing and charging, including design choices for where to install charging stations. The aim of the paper is to illustrate and discuss the effects of solving the timetabling and vehicle scheduling of electric buses (including where to install charging infrastructure) separately, compared to solving them jointly in one single step. For that purpose, we perform tests with: i) given timetable, that is, solving only the vehicle scheduling problem, ii) fixed headways for each line, and iii) variable headways. A small test case based on actual bus lines from V{"{a}}stra Fr{"{o}}lunda, Gothenburg, Sweden, is used. From the numerical experiments, we verify that combining the two planning steps can significantly reduce the number of vehicles needed.

Optimal charging station locations and durations for a transit route with battery-electric buses: A two-stage stochastic programming approach with consideration of weather conditions

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Esmaeilnejad, S. and Kattan, L. and Wirasinghe, S. C.

> While the environmental advantages of battery-electric buses (BEBs) are well-known, their significant differences from diesel buses require alterations to both route design (i.e., charging station locations) and operations (i.e., schedule management and holding control). The location, number, charging duration, and types of charging stations must be considered as part of the planning process. Charging stations can be located at depots, termini, or en-route. This paper considers the long-term planning and optimization problem of en-route charging station locations and charging duration to optimize passengers' waiting time and operation and capital costs while addressing the weather-induced stochasticity of ridership and battery performance of the BEBs. A linear deterministic optimization model and a two-stage stochastic programming (SP) optimization process are developed to place BEB charging stations along the route and estimate their assigned charging time for both one-way and two-way operations. The developed approaches are tested on two high-demand bus routes in Calgary. The impact of the breakdown of the charging station associated with the maximum charging time on the schedule and the cost of the BEB operation is assessed. The solution of the stochastic model is analyzed using the expected value of perfect information as an index. The results indicate that using

> the SP model helps decrease the expected travel time of the route while the total cost per trip increases compared to the deterministic model.

Optimal locations and sizes of layover charging stations for electric buses

1. Year: 2023
2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: McCabe, Dan and Ban, Xuegang (Jeff)

> Public transit agencies across the world are rapidly converting their bus fleets from diesel or hybrid powertrains to battery-electric propulsion systems. To realize the benefits of the transition to battery-electric buses (BEBs) while retaining acceptable quality of service and limiting capital costs, agencies must intelligently decide where to locate recharging infrastructure. While most agencies electrifying their fleets plan to install chargers at bases where buses are kept overnight, a question faced by many fleet operators is where to install layover chargers that provide additional energy while buses are in operation during the day. To address this challenge, this work presents a mixed-integer linear programming model, referred to as BEB-OCL (BEB Optimal Charger Location), that optimizes the tradeoff between upfront charging infrastructure costs and operational performance. The key decision variables include the locations at which to install chargers, the number of chargers installed at each chosen location, and the location, duration, and sequence of charger visits for each bus. We also introduce a second optimization model, referred to as BEB-BRP (BEB Block Revision Problem), that revises vehicle schedules by dispatching backup buses to serve some trips so that buses do not run out of battery and all passenger trips are still completed as scheduled. The models are applied to a case study of the highest-ridership bus routes in King County, WA, USA, where an electric bus deployment is currently underway.

Optimization of Electric Bus Scheduling for Mixed Passenger and Freight Flow in an Urban-Rural Transit System

1. Year: 2023
2. Journal: IEEE Transactions on Intelligent Transportation Systems
3. Authors: Zeng, Ziling and Qu, Xiaobo

> Transport accessibility and urban-rural connectivity are seen as critical aspects of rural economic development. In the transit network, passenger flow between urban-rural corridors demonstrates directional imbalances and low utilization of scarce resources. Freight transportation, on the other hand, lags due to poor geography, high operating costs, and scattered demand. This paper proposes a new mode of public transit that integrates passenger and freight transport, providing a carrier for logistics while compensating for the low utilization of passenger transport. In this mode, each timetabled round trip is divided into one dedicated passenger trip with high demand and one mixed-flow trip with on-demand requests. A space-time-state network is constructed considering the picking-up time window, loading/unloading service time, and electric bus energy replenishment. A mixed-integer linear programming model is developed to optimize the bus schedule that covers the travel demands and the charging requests with minimized travel costs. A Lagrangian relaxation framework with a dynamic programming algorithm and sub-gradient method is presented for problem-solving. The real-life rural-urban transport instance and a simulated network demonstrate the operation of the new mode and validate the efficiency of the proposed method. The innovative concept and the

> optimization framework are expected to serve as a reference for public administration to alleviate passenger and freight transportation bottlenecks in the urban-rural context.

Optimizing public transport transfers by integrating timetable coordination and vehicle scheduling

1. Year: 2023
2. Journal: Computers and Industrial Engineering
3. Authors: Liu, Tao and Ji, Wen and Gkiotsalitis, Konstantinos and Cats, Oded

> Transfer optimization in public transport (PT) networks can be achieved through coordinated timetabling and vehicle scheduling. Traditionally, the coordinated timetabling problem is solved first before proceeding to the vehicle scheduling problem. The integration of these two problems can help further reduce the total operation cost and improve the level of service, especially when timetables of different PT lines are well-coordinated at transfer stations. This work addresses the integrated PT timetable coordination and vehicle scheduling problem while ensuring that each PT line is dispatched with an even headway. We first separately formulate two integer linear programming models for the timetable coordination and vehicle scheduling problems. Next, the two models are integrated into a bi-objective integer linear programming model for the integrated timetable coordination and vehicle scheduling problem. For small size PT networks, the model can be solved by using an ε-constraint method, together with off-the-shelf optimization solvers. For large-size problems, two constraint-reduction procedures are developed to reduce the number of redundant constraints so as to reduce the computation complexity and improve the solution process. Finally, the models and solution method are applied to a numerical example and a real-world bus rapid transit (BRT) network in Chengdu, China. Computation results show that the solution generated by the sequential optimization approach is usually dominated by the Pareto-optimal solutions generated by the integrated optimization approach. Our findings suggest that it is not a wise decision to use the solution generated by the sequential optimization approach or the solution with the minimum fleet size generated by the integrated optimization approach. For practical implementation, it is recommended to choose the solution that has a fleet size of one more vehicle than the minimum fleet size.

Charging facility planning and scheduling problems for battery electric bus systems: A comprehensive review

1. Year: 2024
2. Journal: Transportation Research Part E: Logistics and Transportation Review
3. Authors: Zhou, Yu and Wang, Hua and Wang, Yun and Yu, Bin and Tang, Tianpei

> The adoption of battery electric buses (BEBs) has gained significant momentum in the public transportation sector due to their environmental and energy-saving merits. Nonetheless, challenges such as limited driving range and battery degradation, to some extent, hinder the extensive deployment of BEBs. This paper provides a comprehensive review of BEB adoption and utilization over the past decade, categorizing the state-of-the-art development and our discussion on BEB charging facility planning (BEB-CFP) and BEB charging scheduling (BEB-CS). In this review paper, we first survey the prevailing charging technologies in the BEB market and evaluate their applicability and limitations. Subsequently, the paper synthesizes the development and application of these technologies in terms of related infrastructure planning and charging scheduling operation, focusing on their unique considerations, modeling approaches, solution algorithms, and practical applications. Last, the paper

> concludes by identifying avenues for future research. Our findings contribute to the literature by providing a holistic revisit of BEB-CFP and BEB-CS with different types of charging technologies, offering selection recommendations and insights for both practitioners and policymakers aiming to optimize the utilization and sustainability of BEB fleets.

Co-optimizing the smart grid and electric public transit bus system

1. Year: 2024
2. Journal: Optimization and Engineering
3. Authors: Yetkin, Mertcan and Augustino, Brandon and Lamadrid, Alberto J. and Snyder, Lawrence V.

> As climate change provides impetus for investing in smart cities, with electrified public transit systems, we consider electric public transportation buses in an urban area, which play a role in the power system operations in addition to their typical function of serving public transit demand. Our model considers a social planner, such that the transit authority and the operator of the electricity system co-optimize the power system to minimize the total operational cost of the grid, while satisfying additional transportation constraints on buses. We provide deterministic and stochastic formulations to co-optimize the system. Each stochastic formulation provides a different set of recourse actions to manage the variable renewable energy uncertainty: ramping up/down of the conventional generators, or charging/discharging of the transit fleet. We demonstrate the capabilities of the model and the benefit obtained via a coordinated strategy. We compare the efficacies of these recourse actions to provide additional managerial insights. We analyze the effect of different pricing strategies on the co-optimization. Noting the stress growing electrified fleets with greater battery capacities will eventually impose on a power network, we provide theoretical insights on coupled investment strategies for expansion planning in order to reduce greenhouse gas (GH) emissions. Given the recent momentum towards building smarter cities and electrifying transit systems, our results provide policy directions towards a sustainable future. We test our models using modified MATPOWER case files and verify our results with different sized power networks. This study is motivated by a project with a large transit authority in California.

Framework for Considering Electrification of Bus Routes: Demonstration Experiment Using Osaka University Inter-Campus Shuttle Bus

1. Year: 2024
2. Journal: IEEJ Transactions on Industry Applications
3. Authors: Sakai, Katsuya and Ota, Yutaka

> This research presents a comprehensive framework for electric bus power consumption and charging systems based on the type of electric bus and charging conditions. The power consumption model ranges from a study model before electric bus operation to a more elaborate model in which the electric bus is equipped with a global positioning system logger and current sensor. The electric bus power consumption and fluctuation characteristics are clarified using Osaka University's inter-campus shuttle bus as an example based on given schedule data and the actual driving record. The demonstration experiment is useful for future bus electrification and energy management.

Integrated timetabling and vehicle scheduling of an intermodal urban transit network: A distributionally robust optimization approach

1. Year: 2024

2. Journal: Transportation Research Part C: Emerging Technologies
3. Authors: Xia, Dongyang and Ma, Jihui and {Sharif Azadeh}, Sh

> Integrating emerging shared mobility with traditional fixed-line public transport is a promising solution to the mismatch between supply and demand in urban transportation systems. The advent of modular vehicles (MVs) provides opportunities for more flexible and seamless intermodal transit. The MVs, which have been implemented, are comprised of automated modular units (MUs), and can dynamically change the number of MUs comprising them at different times and stops. However, this innovative intermodal urban transit brings with it a new level of dynamism and uncertainty. In this paper, we study the problem of jointly optimizing the timetable and the vehicle schedule within an intermodal urban transit network utilizing MVs within the context of distributionally robust optimization (DRO), which allows MVs to dynamically (de)couple at each stop and permits flexible circulations of MUs across different transportation modes. We propose a DRO formulation to explore the trade-off between operators and passengers, with the objective of minimizing the worst-case expectation of the weighted sum of passengers' and operating costs. Furthermore, to address the computational intractability of the proposed DRO model, we design a discrepancy-based ambiguity set to reformulate it into a mixed-integer linear programming model. In order to obtain high-quality solutionss of realistic instances, we develop a customized decomposition-based algorithm. Extensive numerical experiments demonstrate the effectiveness of the proposed approach. The computational results of real-world case studies based on the operational data of Beijing Bus Line illustrate that the proposed integrated timetabling and vehicle scheduling method reduces the expected value of passengers' and operating costs by about 6% in comparison with the practical timetable and fixed-capacity vehicles typically used in the Beijing bus system.

Life-Cycle analysis of economic and environmental effects for electric bus transit systems

1. Year: 2024
2. Journal: Transportation Research Part D: Transport and Environment
3. Authors: Pei, Mingyang and Hu, Yi and Han, Weiji and Qu, Xiaobo and Zou, Changfu

> Electric buses play a crucial role in reducing the carbon footprint. This study evaluates the life cycle costs (LCCs) and environmental impacts of three e-bus transit systems: stationary charging, battery swapping, and dynamic wireless charging. A mixed-integer nonlinear optimization problem is formulated to determine the optimal design parameters for the charging infrastructure, bus fleet size, and battery capacity for each e-bus transit system considering battery degradation. Taking Guangzhou's Bus Rapid Transit (BRT) system as an example, a sensitivity analysis of the optimized solution is conducted. The LCC analysis framework is extended to BRT systems in 38 cities globally. The results indicate the superiority of battery swapping in most cases, while stationary charging and dynamic wireless charging are more competitive in cases with long circuit lengths and high service frequencies. Dynamic wireless charging becomes the best option when charging infrastructure is shared with other bus lines or private cars.

Operation estimation on multiple public transport timetables integrated with vehicle scheduling in practice

1. Year: 2024
2. Journal: Transportation Letters
3. Authors: Cao, Zhichao and Wang, Yaoyao and Zhang, Silin

> Even-headway and even-load timetables have been in practice for the past 50 years. The former stipulates constant departures to cultivate users' habits accordingly, whereas the latter is oriented from demand regulations aiming to further reduce waiting times. However, striking the balance between operation reliability (derived from even-headway timetabling) and an on-demand response to passenger fluctuation (referring to even-load timetabling) requires addressing major challenges presented by peak or alternatively off-peak demands. Our work addresses this imbalance by comparable estimation. The focused problem involves timetabling, vehicle scheduling, fleet size, and operation reliability based on an identical modeling framework simultaneously involving the three models. Nonetheless, their compatibility warrants a unified measure estimation. Hence, a mixed integer linear programming model is built. Finally, multiple timetabling performance comparisons are observed by the Auckland public transport system yielding sensitivity analysis.

Optimising modular-autonomous-vehicle transit service employing coupling–decoupling operations plus skip-stop strategy

1. Year: 2024
2. Journal: Transportation Research Part E: Logistics and Transportation Review
3. Authors: Zhang, Jiyu and Ge, Ying En and Tang, Chunyan and Zhong, Meisu

> Modular autonomous vehicles (MAVs) have enormous potential to accommodate spatio-temporally imbalanced demand by coupling and decoupling flexibly in operation. The existing work in the literature on MAV service mode design is focused on the matching between supply and demand not at the bus-stop level but at the bus-route level. To fill the gap, this work proposes a novel MAV service mode that incorporates coupling–decoupling operations en route plus skip-stop strategy and simultaneously determines the number of MAVs and headways required for each trip, MAVs' coupling and decoupling scheme, and each MAV's skip-stop scheme. A mathematical programming formulation is devised to minimize the total cost of a transit service to the operator and to the passengers by using a trip-extended network approach while environmental impacts of energy consumption savings are considered with the operation of coupling multiple MAVs as a platoon. A case study of a real-world bus line in Dandong, China, shows that, compared with the prevailing service modes with no coupling–decoupling operation at intermediate stops or a skip-stop strategy, the mode designed in this work reduces the total cost of the transit system by 9.87%–32.09% and the passenger travel cost by 17.92%–38.54%.