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Factors Affecting Commuter Rail Energy Efficiency

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TECHNICAL SUMMARY

Title

Factors Affecting Commuter Rail Energy Efficiency

Introduction

The purpose of this research is to identify and analyze factors affecting commuter rail system energy efficiency and its comparison with competing passenger travel modes.

As concerns about the environmental impacts and sustainability of the transportation sector continue to grow, modal energy efficiency is increasingly important when evaluating the benefits and costs of future transportation system investment in commuter rail operations. Increased energy efficiency of passenger rail systems compared to other modes is often cited as a justification for new investment. Commuter rail is best characterized as a passenger rail service operating between a downtown area of a major city and the outlying suburban areas on conventional railroad infrastructure. In many metropolitan areas, this trackage may be shared with freight rail operations. Commuter rail typically moves riders longer distances within the greater metropolitan area of a city or region, compared to light or heavy rail rapid transit that more typically moves passengers within the city, or intercity passenger rail that covers longer distances between cities and metropolitan regions. Environmental concerns of energy efficiency and emissions reductions are integral in regional planning, especially in urban areas where highways and roads can become increasingly congested. Commuter rail in the United States (US) has experienced a renaissance in recent years, with rapid growth both in ridership and the number of systems in operation. Commuter rail ridership increased by 28% between 1997 and 2007 and by nearly 13% between 2008 and 2012, for a total combined increase of 49%.

Operating energy consumption is a vital consideration in the economic justification of commuter rail projects, representing a large portion of the long-term system operating expenses. In the planning stages of a commuter rail project, the costs and benefits are often based on national averages. However, as this project demonstrates, operating energy efficiency varies with many factors such as vehicle type, energy source, interference from other trains, service frequency, stopping patterns, average speed, and consist make-up.

Approach and Methodology

This report investigates factors affecting commuter rail energy efficiency and its comparison with competing passenger travel modes. To accomplish this, data from the National Transit Database were analyzed to demonstrate various methods of quantifying the energy efficiency of commuter rail systems and to identify trends in commuter rail system energy efficiency in the US. In parallel, statistical analyses of simulation results from Rail Traffic Controller show the effects of several operational and infrastructure parameters on passenger rail energy efficiency. The Multimodal Passenger Simulation (MMPASSIM) tool was used to simulate the movements and energy efficiency of several commuter rail case studies to investigate the influence of alternative patterns of train station stops. This tool was also used to investigate the effects of energy-saving technologies and strategies on the commuter rail case study services, and to compare the results to competing passenger travel modes including automobile and bus.

Findings

After reviewing the literature, it was evident that past studies often conducted energy efficiency analyses and modal comparisons using methods that favored one energy source or competing mode by neglecting losses in the system. Therefore, four methods of energy efficiency analysis were identified and applied to 25 commuter rail systems in the United States using data from the National Transit Database (NTD). Using the same database, an analysis of trends in energy efficiency exhibited by the United States commuter rail systems was conducted. On a gross annual average, the energy efficiency of commuter rail remained largely constant over the past 15 years. Despite dramatic increases in ridership, the load factor of the commuter rail systems in the US has also remained nearly constant.

Further findings from simulation of commuter rail operations with the Multimodal Passenger Simulation Tool (MMPASSIM) are detailed in the following section.

Conclusions

As concerns about the environmental impacts and sustainability of the transportation sector continue to grow, modal energy efficiency is increasingly important when evaluating the benefits and costs of future transportation system investment. The energy efficiency of passenger rail systems compared to other modes is often cited as a justification for new investment in commuter rail. Previous research has used statistical, empirical, and analytical methods to evaluate the environmental impacts of transportation projects. Research on the energy efficiency of commuter rail systems must be tailored to the purpose of the study to most accurately analyze and fairly compare the energy intensity of competing traction types, vehicle types, and competing modes. Gross annual average analyses use aggregate energy consumption and transportation productivity values to describe the efficiency of systems as a whole. However, these studies are unable to illustrate the energy efficiency differences between individual trains or peak/off-peak periods with varying passenger loads. Empirical analyses where energy consumption is measured from in-service train movements can be extremely accurate and detailed, but lack applicability to general conclusions across systems with multiple equipment and service types. Simulation models offer a compromise between annual averages and empirical analyses. They offer a low-cost methodology for evaluating various equipment, route, and service alternatives, but require more detailed input data characterizing the route and vehicles.

Past studies approach the problem using each of these methods. However, these studies often draw comparisons between traction types or competing modes at unequal points along the energy flow path of each system. This tends to neglect energy losses along the energy flow path, and may overstate the benefits or costs of using a specific traction type, vehicle, or transit mode. Four methods to analyze the energy efficiency of electric and diesel-electric traction rail systems were identified in this research, each corresponding to points along the energy flow path: *traction analysis*, *purchased analysis*, *energy conversion analysis* and *upstream analysis*. Each can be useful depending on the particular question or application under consideration. Traction analyses provide the most basic measure of the efficiency of passenger rail coaches, analyzing the energy efficiency from the traction motors to the wheels. Purchased analyses are useful proxies for the economic efficiency of commuter rail systems because energy consumption directly purchased by operators is used, while energy consumption used upstream or by electricity generation is ignored. Energy conversion analyses are useful in comparisons between rail systems or competing modes because the energy used in electricity generation is included. Upstream analyses can be useful in assessing the environmental impacts of rail systems outside of the operator's boundaries, such as in a city or region. The application of the four methods to the United States (US) commuter rail systems serves as a framework for use with annual average statistics, but can also be applied to empirical or simulated energy consumption data.

Using a variation of the traction analysis method, an analysis of the US commuter rail systems was conducted using annual energy consumption data from the National Transit Database. Results show that despite large ridership growth, energy efficiency of the national commuter rail systems has remained nearly constant over the past 15 years. New-start systems tend to have a higher energy efficiency than legacy systems, indicating the use of newer, more energy efficient rolling stock.

To understand the factors affecting passenger rail energy efficiency, Rail Traffic Controller (RTC) was used to conduct single-variable and multi-variable analyses of passenger rail on a single-track corridor shared with freight trains. Single-variable analyses indicated that station spacing and gradient had a large impact on passenger train fuel efficiency. Multi-variable analyses indicated that all of the variables analyzed (train length, number of locomotives, traffic volume, speed, traffic heterogeneity, gradient, and station spacing) had impacts on passenger train fuel efficiency, and that all factors should be considered in efforts to improve energy efficiency through modeling.

Simulations using the Multimodal Passenger Simulation Tool (MMPASSIM) indicated that alternative timetable patterns can reduce total peak-period energy consumption compared to local trains that stop at every station along a line. Using a constant train consist for each run, express patterns (a combination of local and zonal trains) consumed the least energy during the peak period. When the consist size varied according to passenger demand along the line, the skip-stop scenario consumed the least energy during the peak period. Pareto-optimal curves of energy consumption versus passenger travel time illustrated a trade-off between the two metrics. Optimization models could be developed using this framework to meet minimum service constraints while also minimizing passenger travel time and energy consumption.

MMPASSIM was used to evaluate the effectiveness of strategies and technologies to reduce energy consumption or improve levels of service on a Midwestern US commuter rail service. Results indicated electrification of the existing infrastructure and a switch to electric motive power had the greatest potential to reduce operating energy consumption, reducing energy intensity by 29%. However, this strategy requires large investments in the infrastructure. Driver advisory systems to aid the driver in optimally coasting into stations, depending on schedule slack, reduced energy consumption by an average of 23% and require lower investment. Service improvements, such as decreasing travel time by increasing speeds or available horsepower, led to reductions in travel time but increases in energy intensity, further indicating a compromise between travel time and energy consumption.

Comparisons between the same Midwestern US commuter rail service and equivalent automobile and bus trips using MMPASSIM indicated that commuter rail is the least energy intense mode under off-peak and peak congestion levels. Implementation of alternative timetable patterns (such as zonal and skip-stop) reduced the energy intensity of the rail trip, increasing the difference between the energy intensity of rail and competing modes. Load factor equivalency charts showed lines of equal energy intensity over all possible combinations of rail and competing mode load factors. MMPASSIM and the simulation framework shown can help commuter rail operators and public policy makers analyze the environmental benefits of investments in passenger transit modes.

Recommendations

The quality of energy efficiency analyses can be improved by improving the quality of input data available to researchers. For several chapters in this thesis, the National Transit Database was used to analyze the energy efficiency of US commuter rail systems. The database provides a wealth of data that can be useful in continued research on the topic. Even so, the quality of the database can be improved to increase its applicability to academic research. One issue identified during the analyses was inconsistencies in reported data. Several fields had reported data that differed from what is requested by the NTD. For example, system mileage was reported by some agencies as track-miles (distance of individual track) versus route-miles (distance along routes, regardless of the number of tracks). Inconsistencies in reporting between operators can skew energy efficiency analyses attempting to find relationships between reported values and energy consumption.

MMPASSIM is a useful simulation tool for operators interested in evaluating the energy consumption of their rail movements because operators will have access to a wealth of input data regarding their track geometry, equipment resistance characteristics, and operations. This type of data may often be challenging for academic researchers to obtain because commuter rail operators often use private freight railroad property. This can be problematic when gathering track geometry data. Train resistance-related data and locomotive fuel consumption data are generally proprietary and difficult to find in published literature. Increasing the availability of such data will be helpful to researchers by providing robustness to simulation models such as MMPASSIM.

As shown by the analyses of the effects of peak-period schedule patterns and service-improvement strategies on energy intensity, a trade-off between improved service (reduced passenger travel time) and energy consumption exists. Commuter railroad operators strive to provide the best service to passengers, but are increasingly budget-constrained and aiming to reduce operating costs by improving energy efficiency. This research identifies a number of factors affecting energy efficiency and can serve as a starting point for the development of models to find the optimal balance between reduced travel time and energy consumption.

Finally, modal comparisons are useful for evaluating the environmental impact of passenger transportation options for future investment; however, passenger transportation is a multimodal system. Passengers use several modes to complete each trip from origin to destination (door-to-door). Although this feature was not used in this thesis, MMPASSIM has the capability to evaluate the energy efficiency of door-to-door trips, including the modes used to access and egress the main segment of a passenger trip. With the environmental movement growing, passengers may be interested in understanding more about the environmental impact of daily trips. It is possible to apply the capabilities of models like MMPASSIM to navigation software, such as Google Maps, to offer users the energy consumption for equivalent trips on competing modes alongside standard metrics like distance and travel time.

Publications

Master's Thesis for Giovanni Didomenico, attached

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