Evaluation of a Plug-in Electric Shuttle to a Rural Community as an Initial Transit Service

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Abstract

The use of fixed route public transportation systems within small to medium sized rural communities has not been considered feasible due to the population density. This research describes an effort to install a fixed route plug-in electric public shuttle bus into a semi-rural town of 20,000 residents. The change adoption and technical integration of this shuttle was examined in terms of route analysis, travel duration, rider capacity of the shuttle, and choice of destinations in and around the town. The analysis of these design variables, within this transportation system, identified the opportunity to apply this town's first public transportation shuttle. The electrical needs of the bus were also considered as a factor, due to its departure from common fossil fuel vehicles. The expected capacity of regions within the transportation area, the traffic infrastructure, and the probable destination points were plotted within the region and assigned a hierarchy. That order defined the criteria for where and how often the bus would need to collect its patrons. As this is the first public transportation service of the area, the data and analysis were collected from estimates of the city's population and notable destinations for the community.

Keywords
Engineering Management, Public Transportation, Electric Transit
1. Introduction
Many concepts drive the adoption of public transportation services within urban areas, including vehicular congestion, pollution mitigation, and lack of transportation alternatives. Benefits of public transit are now being considered as part of sustainability focused initiatives like energy demand, oil dependency, and clean cities projects. At its most fundamental, public transportation uses a service, like fixed route travel, to increase the efficiency of its energy, by increasing the number of passenger-miles traveled. Within urban, congested, and populated areas, the benefits of public transportation are obvious. In more suburban or rural areas however, the benefits of public transportation tend to be more abstract or intangible. While rural public transit still offers the benefit to congestion, pollution, and the needs of transportation to the population, the effective use of the service is more difficult to quantify, and thus more difficult to justify its costs. This work defines an evaluation method to analyze the effectiveness of an initial launch of a fixed route plug-in electric bus to a rural community. An analysis of the ridership demographics provides feedback that enables the transit manager to evaluate the components of the public transit systems including destinations, loop duration, and use of the public transit systems. A framework for evaluating effectiveness is presented.

The Missouri University of Science and Technology, within Rolla, Missouri is the test case for this research. Rolla serves as the example of a small rural community implementing a new public transit system. The test scenario is a plug-in electric 30 passenger shuttle expected to travel between the university’s academic corridor and some of its external housing facilities. In this example, the bus route has been determined by a series of high traffic locations in and around points of the university. The destination stops beyond the residential areas were chosen due to proximity to academic, recreational, or functional centers of campus. The route and its effectiveness to the community have not been analyzed to evaluate a best possible route and were assigned using calculated route path heuristics within the public transit industry.

This work develops an evaluation tool around the ability to analyze the needs of its riding population, compared against the functional ability of this transit component, and the financial feasibility of an effective route. Elements of each of these variables; social, economic, and technical, are compiled to evaluate the functionality and usefulness of this initial single unit public transit system.

2. Literature Review
The introduction of a new public service to a community demands the consideration of many of the social implications. This is especially true within small towns and rural populations. In communities like Rolla, Missouri, a city of less than 20,000 residents, and the example city of this work, social perception of a new service is critical to its eventual performance. As Taylor et al. describe in their work on ridership, many factors within urban and rural transit systems exist to explain ridership, but the majority of their findings suggest that timeliness and cost are some of the most significant contributions of the service. [1] This social reaction highlights the needs of the population most likely to utilize this service. The population most in need of the public transport system is concerned about the cost per ride and how often the service is available. These are some of the functional requirements of this public transit system. Guerra and Cervero also note that the cost of the ride is a concern in their discussion on ridership versus capital investment. [2]

Zhou notes that, in regard to university students, such as the students within the test case, age and gender are also characteristics evaluate in ridership studies. [3] Analysis of the ridership demographics within the test case should be robust enough to evaluate age and status.

The American Public Transportation Association (APTA) describes in their publication that the uses of public transportation within small urban and rural settings tend to share many of the same destinations as their large urban counterparts. [4,5] According to APTA, getting to work, shopping and dining, as well as getting to school accounted for some of the highest percentages of the population surveyed. In this regard, the areas with the highest densities that include these types of destination stand to be some of the most visited throughout the public transit service. This is confirmed by APTA’s on-board surveys of ridership demographics, in urban, suburban, and rural areas.

Energy systems are also an important consideration when discussing public transit. Whether in regard to the amount of energy used in transportation annually or the volume of oil the United States imports from foreign nations, the amount of energy that is used in transportation within the United States is impressive, compared to many other developed nations. According to the Energy Information Administration (EIA), the amount of energy the United States
Brennan, Long

used on transportation in 2011 was roughly 27.08 quadrillion BTU of energy. Transportation was the second highest consumer of energy and accounted for 27.6% of the national energy consumption. [6] With the adoption and investment in public transportation, the number of vehicles on the roads and highways reduce. This reduction in vehicles can lead to a reduction in the energy use, congestion, and pollution. However, according to the Transportation Energy Data Book, buses only accounted for 0.7% or 194.4 trillion BTU of energy in 2011. [7]

![Figure 1: United States Energy Flows 2011.](image)

Behavior and change adoption within rural public transit are necessary to control. In a multi university study of campus commuters, Fu et al. attempted a number of behavior and change adoption methodologies to encourage ridership and evaluate behavior within the public transit community. [8] Shannon et al. also attempted behavior change methodology within their university in Australia, using a series of incentives and disincentives to promote positive change in behavior, while negatively affecting other options. [9]

3. Methodology

This research develops a routing schema using calculated route path heuristics and ridership demographics. The development of a routing system is based primarily on social and geographic requirements of the population in addition to the functionality of the transit components themselves. With university residents, like the sample population, the needs and interests of the population can be developed through the common needs of the university’s students, staff, and faculty. For example, the students and faculty require access to the academic corridor of the university, while the staff population needs access to administrative and support facilities. Understanding the populations and the sub populations defines many of the characteristics necessary to identify the destination. Centers of high population density and high interest are also necessary to consider as destinations which can be derived from census and surveyed data. Data from many different sources is necessary to evaluate the functionality of a destination and that functionality must be compared against the usefulness to the service as a whole. For example, a destination that services a highly used area within the community, but adds considerable amount of travel time may be useful to some or all of the population, but would negatively affect the ridership due to extending the travel time of the route. As Taylor described, the route duration and timeliness was one of the main components of ridership. [1]

Collection of the ridership data is important to understanding the population of the community, and in turn, the effectiveness of the service. The process of collecting that demographic data from the riders is also very important. When, where, and how often the population chooses to utilize the public transit service is critical data to collect. This must be accomplished without impeding the flow of the incoming riders onto the shuttle. [1,3] The sample test will install data collection methods, such as an ID card reader, that reads information from the student, faculty, and staff identification cards. This card reader will track entry onto the bus with a time stamp, location, name, gender, and faculty, student, or staff status, along with other non-directory information specific to Missouri S&T. The collection of data within the test community allows for validation of the destinations, duration, and effectiveness of the shuttle within the service community. Once the data collection period for this community has ended, the statistics from this test will be used to evaluate the effectiveness of the service and the effect within the community. Within a standard community, however, where institutionally issued identification is not common, options are limited to providing a bus
pass ID card linked to user-provided demographic information at a cost to the rider. Or it is possible to forego the demographics information in exchange for the simpler people counting option. Communities where demographic information is inaccessible, people counting options provide the ability to track the number of patrons to the service, but fail to help evaluate the efficiency of the route or its destinations.

Cervero and Kockelman suggest their analysis of the 3D’s: density, diversity, and design. [10] The analysis of the built environment surrounding the public service noted that the amount of people and destinations that could be designed into a single built environment could benefit the entire community. The route determination used within the test case at Missouri S&T was assigned using the characteristics for the community and its population.

According to Hafezi and Amiruddin in their work on traveler time duration and wait times, they suggest that the time spent in-vehicle and at the boarding location are another reason why passengers tend not to pursue ridership on public transit. [11] Yoh et al. also suggest that the longer the wait times, generally the more investment is expected at the waiting area and the service facilities. [12] This is done to support the needs and wants of the waiting crowds while the bus is in transit to or from their location.

Rider capacity is another functional limit based on the shuttle specifications. The capacity is defined as the number of riders capable of traveling at once. It accounts for how many seats and standing positions are available on the shuttle. With an analysis of the destination areas and population, as well as expected ridership, the necessary capacity of the bus can be calculated weighing the physical risk of having empty seats compared to the societal risk of having too few seats and having to turn people away until the next bus arrives. Having the perfectly sized bus to accommodate the need would be ideal, but primarily bus manufacturers design and build certain styles and have a rated capacity. Small scale rural units, like the example bus in the test case, are predominantly a smaller variety of shuttle. The test shuttle seats 22 passengers with additional space for 10 standees.

There are some elements outside the system that will interact with the shuttle and its operation. Traffic and civil infrastructure affects the travel time and ability for the bus to maintain a rigid schedule. For most cases, traffic congestion within rural communities will not have a large effect on the operation of the schedule, but the civil infrastructure of the community could. Civil infrastructure might include traffic lights or traffic signage into the shuttle route. These elements are generally outside the shuttle’s control, and traffic law must be followed to avoid incident, but they can impact efficiency and timeliness.

Unlike a fossil fuel vehicle, an electric shuttle needs a charging station to refuel the battery pack. The electrical requirements of the shuttle charger must be met in order to fully, and reasonably quickly, charge the battery.
4. Analysis Framework
This evaluation framework combines the demographics data of the population, density, and interest data from the community and technical functionality data from the capabilities of the public transportation components, in this case a plug-in electric bus.

The route is the combination of destinations and travel duration. The data collected from the community to represent areas of interest should relate to the areas most seen within the APTA’s example of where riders are visiting. [5] Primarily, public transit in small urban and rural areas is used for transportation to work, shopping and dining, and school. These destinations should be weighed against the dense center of population for each style. By weighing each destination style, dense areas of the community can be accessed for their functionality in one or all of the destinations. Such that if the sample population is distributed like the APTA data, and sample Area A is near a work center of the town, but has no proximity to schools, or shopping, it may not be a good location for a public transit location. Comparatively, if sample Area B is within a walkable distance to two schools, a work center, and a shopping district, it could be a better option than Area A. The mathematical representation can be seen in Equation 1.

\[
D_{i,j,k} = \text{Destination}_{\text{Work,Shopping,School}} = 35\% \times i + 17\% \times j + 11\% \times k
\]

Population proximity is also a concern when distributing destinations. Similarly to the destination styles, a rider must have easy access to enter the transit system from their work or residence. An evaluation of the resident population within a walkable distance to the transit stop is also important to understand. Census data and real estate reports can evaluate the number of residents within population areas, but an understanding of the demographics within the proposed walkable distance remains unknown. According to El-Geneidy and Canepa, the longest distance an average person would walk to get to a public transit stop is less than half a mile. [13, 14]

\[
\text{MAX(Population) within } (\pi \times 0.5^2)
\]

The length of time between stops and the total travel duration for a single loop within the fixed loop service are discrete durations that will also work for or against ridership of a public service. The travel duration is also a component of the route and destination choice. If a rider believes it will take too long to reach their desired location via the public transportation, many will opt for a different transportation option, if available. The inter-travel duration is the time between stops and is calculated by accessing the average speed the service can achieve during travel multiplied by the distance and adding the expected time stopped for passenger unloading and loading. Equation 3 defines inter-travel time for a single distance traveled.

\[
\text{Intertravel Time}_i = V_i(\text{mph}) \times L_{1,2}(\text{miles}) + (T_1(\text{minutes})/60)
\]

Travel duration is the time it takes to complete all the stops on the loop and return to the initial location.

\[
\text{Travel Duration} = \sum_i \text{Intertravel time}_i
\]

One of the critical components to the functionality of a public transit system is the limitations of its physical components, especially within an electric public transit service. The distance the shuttle will be able to travel on a single battery charge, or the vehicle’s range, is like the amount of fuel in a diesel or gas shuttle. A fossil fuel vehicle has the opportunity to refuel, without a significant effect on daily operations, while an electric battery may take several hours to fully charge, depending on the charging characteristics. Generally an electric vehicle’s range must be able to support a full day’s operation, and charge in the off hours, or overnight. The range is affected by the operations of the shuttle, the exterior environment, the driver’s ability, and the physical storage ability of the battery itself. Physically the battery is an energy storage device that is charged and discharged to the shuttle. It has a finite amount of storage capability and a finite speed at which it can accept and release power. That amount of stored power is transferred into all the shuttle’s operations, from accessory needs like lighting and climate control, to primary needs like acceleration and braking. The batteries tend to be affected by external conditions like weather, but many times that consideration is battery chemistry specific. The more significant factor to affect the amount of power stored, and ultimately the range, is the driver’s ability.

Driving styles can positively or negatively affect the capable range of the bus. An experienced electric vehicle driver can use components like regenerative braking, if equipped, and easy driving methods, to reduce the strain on the battery pack. An inexperienced driver might attempt quick acceleration and short stopping methods, putting undue impact on the battery pack. For this work, the range will be computed as a function of the battery storage capability, in kwh, and the driver ability, a multiplier from .8 to 1.05. The driver effect will lessen the capabilities of the service.
if employed with a driver with a low multiplier and opposingly, a high driver multiplier will improve the capabilities of the service. The estimates for driver effect will be reevaluated against experimental data once this test case is complete. Equation 5 describes range in number of full cycles, \( N \), that can be performed on a full charge given \( X \), the ability of the driver, \( Y \), the amount of energy consumed in kwh per cycle, and \( Z \), the full charge of energy, in kwh.

\[
Range \ N = X \ast \left( \frac{Z}{Y} \right)
\]  

(5)

Data collected from the Missouri S&T sample population will be analyzed after its initial data collection period to evaluate the effect of the decision making process of the shuttle planning team and the effect upon the community of riders.

**5. Preliminary Results**

The design elements within the electric shuttle bus application range from the geographical, to the social, to the technical. The combination of these variables within a public transit system aligns the needs of the demographic population with the expectations of the technology. The population has the opportunity to utilize and benefit from this new service in terms of mobility, energy efficiency, and pollution mitigation. This evaluation method of an existing shuttle system or the initial design of a new system to a community will soon be vetted against the test case in Rolla, Missouri. Once accessed for efficacy, this evaluation can be a design tool for the analysis and design of rural shuttle systems within the United States.

This evaluation framework within the rural public transit industry allows for the application and evaluation of optimal locations that are dependent upon the population and community. Transit operation or transit designers have the opportunity, once this work has been compared against multiple data scenarios, to choose routes and destinations according to the needs and interests of their service population rather than arbitrary assumptions. The effect of an evaluation framework to define the route and the effect of the operation of the shuttle service could benefit the future addition of more public transit venues within suburban and rural areas within the United States and abroad.

**6. Preliminary Conclusions and Future Work**

An analysis of the evaluation framework remains necessary to determine its efficacy, but the development of rigid framework to analyze rural public transit is a crucial first step to creating an effective routing schedule. By verifying this framework it will help promote a change in perception in regards to the concept of public transportation within a rural setting.

This evaluation tool will be validated using additional test data within other communities to assess the confidence of the analysis. The Missouri S&T test data, once collected, will give an initial opportunity to critique this evaluation framework. The population and physical layout of the serviced community are obvious factors within the design of rural transit options, but more analysis needs to be performed to evaluate if other outlying factors, whether physical, social, or otherwise, also have prominent effect on the operation and ridership of rural services.

Personality profiles of the ridership population would also facilitate a more in depth understanding of the patrons of the services. Rider profiles could be facilitated by on-route surveys performed across a useful reporting period. These attempts to better understand the population could benefit this evaluation framework by assessing needs and interests around travel duration, destination choices, and a myriad of other transit focused decisions.

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