Public Transport Service Quality Improvement Using Universal Design Standards and Advanced Vehicle Technologies

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Abstract. Recent transportation policies have been towards encouraging model shift from private vehicles to public transportation (PT) and hence reduce the adverse effects of private transportation while ensuring the best use of the land resource. Singapore, one of the most densely populated counties in the world, has been developing policies for a car-lite society such that PT trips will constitute 75% of the morning peak hour journeys. Customer satisfaction is the main determinant in travel's mode choice. Therefore it is of paramount importance to serve the increased demand while improving the customer satisfaction. A semi-rapid transit (SRT) system is currently being developed for Singapore which aims to aims to complement the current PT systems of Mass Rapid Transport (MRT) subway and busses. The SRT vehicle is designed to incorporate the Universal Design (UD) Principles as well as the advance vehicle technologies such as autonomous driving and electric powertrain. This paper discusses how the implementation of the UD Principles and vehicle technologies in the new SRT vehicle improves the service quality in terms of comfort, accessibility, security, information, and environment. The service quality aspects are compared with those of the current bus system.

Keywords: public transportation, service quality, Universal Design Principles, autonomous vehicles, electric vehicles

1. Introduction

Policies to bring about modal shift from auto dependence to public transportation (PT) have been a key area of interest for transportation authorities not only to reduce externalities caused by the use of private cars but also to reduce the land devoted to private cars and hence to provide more space to people. PT service quality reflects the passengers' perception of service quality and influences traveler's choices significantly. Service quality is defined as the extent by which an organization meets or exceeds customer expectations (*1*). It can be assessed in terms of the gap between customer expectations and the perceived service (*2*). If performance does not meet the expectations, then the perceived quality is less than satisfactory and customer is dissatisfied (*3*). Therefore, customer satisfaction is believed to be a major driving factor for retaining existing PT users as well as attracting new ones (*4*).

In cities with high population density and limited land resources like Singapore, it is of paramount importance to make the best use of the land resource while taking sustainable development into account. As of 2012, public transportation trips constitute only 49% of the total trips and 63% of the peak hour trips in Singapore (*5*). The Land Transport Authority (LTA) in Singapore has highlighted the need to move towards "car-lite" society in the document of the Sustainable Singapore Blueprint 2015. The Sustainable Singapore Blueprint 2015 outlines the national vision and plans for a more livable and sustainable Singapore by year 2030. The plan aims for "car-lite" society where transit trips make up for 75% of morning peak journeys (*6*) as well as active travel modes such as walking and cycling reducing the reliance on motorized vehicles (*7*, *8*). Singapore also plans to limit vehicle growth to zero percent by mid-2018 (*9*).

Singapore features a sophisticated and a well-designed public transport system consisting of a Mass Rapid Transport (MRT) subway system and a dense network of bus lines. Suburban living areas are further connected to the MRT by a Light Rail Transit (LRT) system. Although the current public transport layer structure in Singapore has been sufficient to satisfy the current demand for public transport in the past, it will not fulfill the transit demand in the very near future with the cap on the growth of private vehicles. Therefore, achieving 2030 targets would require new concepts that complement and enhance existing ones. Satisfying transport demand at acceptable comfort (*10*) and convenience levels will still be challenging, even after all the planned public transport network improvements such as doubling the MRT lines by 2030 and increasing the number of buses and bus lines are implemented.

One possibility to improve the quality of the public transport service is to introduce additional public transport layers to complement the existing system. Hence TUMCREATE initiated a project to develop an agile Semi-Rapid Transit (SRT) layer that would fill the gap between MRT and bus while re-organizing the urban road space in the most efficient way. The SRT systems are designed to operate autonomously by smart traffic control with modular vehicle platoons. The new system is designed to improve the service quality and efficiency of the transit systems in Singapore. The introduction of new technologies such as electro-mobility and autonomous driving along with the application of Universal Design (UD) standards in the design of the public transport vehicle may help improve the customer satisfaction and hence the service quality.

Until now, Universal Design has been mostly applied for urban planning – mainly for station design – with a strong focus on accessibility (*19, 20, 21*) without any consideration of incorporation of advanced vehicle technologies. Similarly, lack of accessibility to specific bus stops for people in wheel chair has been highlighted in some cities, which is stated as discrimination to disable people who encounter thereby safety issues, reduced quality of life and social exclusion [1, 2, 3]. In most cases, the UD principles are applied to public transportation for only one user group (i.e., with reduced mobility) and for only one indicator (i.e., accessibility). However, the UD principles cover more than one user group and one indicator (cf. chapter 3.2). Indeed, Fearnley (2011) underlined that UD can provide benefits to not only special need groups but also to all passengers. For example, if access depends on the use of special equipment such as a lift, either vehicle-mounted or mobile at a station, the majority of passengers gain no benefit from the improvement; however in the case of low-floor vehicles or level boarding from a platform, it may improve ease of use for all passengers as highlighted by the United Nations Development Programme (*20*).

Furthermore, the benefits should not be only focused on improvement of accessibility, but also of comfort and information, leading to increase satisfaction of all customers regarding the public transport facilities.

This paper discusses how the universal design principles and vehicle technologies are integrated in the design of the SRT vehicle in order to improve the service quality attributes of comfort, information, accessibility, security, and environment.

To that extent, application of several UD principles (not only accessibility) combined with advanced technologies for an increase of service quality of public transportation for all users has not been considered yet.

2. Methods

2.1. Public Transportation Service Quality

Singapore, with a population of over 5.6 million, is the third densely populated country in the world today. According to the Land Transport Authority (LTA) 2015 Statistics In Brief, the number of average daily passenger journeys using public transport in 2014 was approximately 4.4 million (*11*). Sustaining the public transport users as well as fulfilling the objective of car-lite society requires efficient and high quality public transportation services. Therefore it is of importance that the SRT vehicle improves the public transportation service quality compared to the existing system.

Different studies take into account different attributes in determining public transportation service quality. CEN, the European Community for Standardization, has established the standard EN 13816 (*12*) for defining and measuring public transportation service quality for all over Europe. In EN 13816, customer satisfaction refers to the degree to which the customers' expectations and requirements are satisfied by the public transportation provider. It takes into account eight service aspects: availability, accessibility, information, time, customer care, comfort, security, and environment. Availability concerns the extent of services offered in terms of space, time, transport mode, and frequency. Accessibility is defined as the access to the public transportation systems. Information refers to the systematic provision of knowledge about a public transportation system in order to assist the planning and execution of journeys. Time refers to the aspects of time related to the planning and execution of trips. Customer care concerns the attitudes of the public transport operator's employees towards the customers. Comfort refers to service elements introduced in order to make public transportation trips relaxing and enjoyable. Security concerns the personal protection experienced by customers against accidents and crimes. Environmental impact is defined as the environmental impact resulting from the public transportation service provisions. This paper assesses how universal design standards and advances in vehicle technology may improve the service quality using CEN standards.

2.2. Universal Design

The changing demographics, aging population, around the world resulted in the emergence of the Universal Design (UD) concept, which takes into consideration the need of all common people. UD concept generally refers to a user-centred strategy that aims to accommodate the needs of people of all ages, sizes and abilities for equitable access, use and comprehension at little to no extra cost (*13*). The strategy can be applied to the built environment, products, and communication systems. The term originated at the Center for Accessible Housing at North Carolina State University in the 1970s. It comprises of seven principles (*14*):

Principle One: Equitable Use means that the design is useful and marketable to people with different abilities.

Principle Two: Flexibility in Use means that the design can serve different preferences and abilities.

Principle Three: Simple and Intuitive Use means that the use of design is easy to understand, i.e., does not require significant cognitive effort.

Principle Four: Perceptible Information means that the design communicates required information effectively to the user, irrespective of ambient conditions or the user's sensory ability.

Principle Five: Tolerance for Error means the design can handle the accidental or unintended actions of the users with minimal hazard and adverse consequences.

Principle Six: Low Physical Effort means the design can be used efficiently and comfortably and with minimum physical effort.

Principle Seven: Size and Space for Approach and Use means appropriate size and space is provided for approach, reach, manipulation, and use for users with different abilities, body sizes, and postures.

The UD principles have long been applied to industrial products to increase their accessibility. The integration of the UD concept into public transportation vehicle design would not only improve accessibility but also the comfort and information, and hence the overall service quality

2.3. Advances in Vehicle Technology

The current public transportation systems are primarily powered by internal combustion engines (ICE), operated by a driver as stand-alone vehicles. The proposed SRT system makes use of the advent in vehicle technologies such as electric powertrain, autonomous driving technology, and interconnected communications to infrastructure (V2X) and other vehicles (V2V). The vehicle technologies to be implemented have been identified based on the current needs of the bus system in Singapore in terms of the service quality. The incorporation of these technologies along with the Universal Design Principles are expected to result in sustainable transportation systems with zero local emissions, less noise, improved efficiency, predictable travel schedule, improved user interface, increased accessibility and increased travel comfort and travel safety.

3. Service Quality Improvements

Current bus systems have taken steps to apply UD principles and advanced technologies in vehicles and stations. However, there are limitations to these applications which are better addressed in the SRT system. This section discusses how the incorporation of UD principles, electric powertrain, autonomous driving functions including 4-wheel independent steering and robotic control systems, as well as improved vehicle functions including lower kneeling height and independent air suspension in SRT vehicle would improve the service quality attributes. Table 1 shows how the service quality attributes of comfort, information, accessibility, security, and environment are improved by integration of the above mentioned technologies and principles to SRT vehicle and stations compared to those of the current bus system. The following paragraphs describe identified drawbacks of bus service and the UD principle(s) they refer to.

Firstly, wheelchair accessibility on current buses is not ubiquitous throughout the system (equitable use); passengers in wheelchairs are constrained to services with wheelchair ramps installed. The ramps, when available, rely on manual operation by the bus captain whenever a wheelchair-bound passenger wishes to board or alight (simple and intuitive use, low physical effort). This situation increases dwell time and as a result, travel time. Additionally, the current fleet in Singapore mostly comprises buses with partially low floor. In the SRT system, the vehicles are fully low floor and ramps are provided at the stations in order to be aligned with the ramp on the vehicle to optimize safety. The increased kneeling capability of the vehicle also helps reduce the door entry height (maximum of 200 mm) and hence the distance between SRT vehicle and the sidewalk which has a height of 150 mm (*15*) combination of a full low-floor vehicle with ramps, higher kneeling capacity, and wider doors provides wheelchair users with leveled access to services across the entire fleet while requiring little physical effort. The feature also extends accessibility to older people and people with disabilities due to greater flexibility of use.

Currently, bus arrival information is available only through smartphone applications and selected bus stop displays, leaving out passengers who do not have access to a smartphone (equitable use, perceptible information). Bus stop identifiers are not always readable from the vehicle while it is traveling, which can cause passengers to alight at the wrong stop, increasing discomfort and travel time (simple and intuitive use, tolerance for error). Similar problems arise from a lack of in-vehicle travel information on current location and upcoming bus stop across the entire bus fleet. Passengers have to rely on smartphone applications with GPS functions to help them navigate their trip. The SRT fleet and stations will feature user-friendly Human Machine Interfaces (HMI) – with design considerations addressing the multicultural population of Singapore – providing station and bus service information to passengers.

Comfort during the bus ride is affected in several ways. The conventional rigid axle air-suspension in the bus causes vibrations, while the internal combustion engine generates high noise levels. The conventional heating, ventilation, and air conditioning (HVAC) system within the bus is prone to energy (thermal) losses when the bus doors open for boarding and alighting, leading to thermal discomfort. Riding comfort is also affected by operator inputs during braking, accelerating/decelerating, and steering. Advanced technology in the SRT system aims to mitigate these issues. The independent air-suspension system increase compliance for uneven road surfaces compared to rigid axle systems, and the electric powertrain leads to significant noise reduction by eliminating the noise at idling as well as reducing the noise during acceleration and operating at low speeds. Further, the SRT vehicle is equipped with a 4-wheel independent steering system, which is designed to retain vehicle maneuverability on narrow roads and turns at intersections. The autonomous driving functions also ensure the acceleration/deceleration rates are within the limits of the passenger comfort. The introduction of an air-curtain HVAC system better regulates the vehicle's temperature for increased thermal comfort. Conventional seat widths of 440 mm may be too narrow to accommodate passengers of different sizes (size and space for use). Therefore, SRT vehicles are designed to have extra wide seats of 660 mm to meet the needs of a more diverse range of passengers.

Current bus fleet in Singapore is operated by drivers meaning that operations are subjected to human errors. Human errors have been found as the major cause of the 94% of traffic accidents (16). Even with the introduction of advanced driver-assistance systems, the accident rate was reduced by 40% (17). Therefore, autonomous vehicles are expected to increase travel safety by elimination human errors. Especially, accidents due to inexperienced or to incapacitated drivers can be avoided. In addition to accident avoidance by autonomous driving technology, the ride safety can be enhanced by the 4-wheel independent steering system. It was shown that a 4-wheel independent steering system can act as an activity stability control during high-speed turns (18). Hence, SRT vehicle is expected to have improved security especially at intersections and junctions.

Conventional buses are detrimental to the environment due to the greenhouse gasses, air pollutants, and noise emitted during the engine's combustion process. The electric powertrain used in the SRT vehicle produces zero local air emissions and eliminates noise generated during idling and at low speeds.

Table 1: Service Quality Improvement Using UD Principles and Advance Vehicle Technologies

Service Quality Indicators	**Current Bus Fleet**	**SRT Vehicle**
Accessibility		Universal Design
	Partially low floor	Fully low floor
	Double door width of 1200 mm	Door width of 1500 mm
	Assistance from the bus captain required for operating the ramps	In-vehicle ramp aligned with the ramps provided at the stations with slopes less than five percent
	Door entrance height of 240 mm	Maximum door entrance height of 200 mm (improved kneeling function)
Information		Universal Design
	Simple Passenger Information System, only displaying the next bus stop	HMI with detailed real-time information on travel options both in the vehicle and at the station
	Static outside signs which tell bus line number and direction	Dynamic exterior visualizations to communicate route information (laser projections on the pavement and LED stripes on the front of the vehicle)
Comfort		Advanced technologies:
	Conventional rigid axle air-suspension	Independent air-suspension system

	Single Axle Steering Driver controlled system High traffic noise level due to internal combustion engine Thermal discomfort due to conventional HVAC system Standard seat width of 440 mm (size and space for approach and use is not guaranteed for all users)	4-wheel independent steering Autonomous driving functions Electric powertrain and thus noise reduction. Air-curtain system for better energy efficiency Universal Design: Extra wide seat width of 660 mm
Environmental impacts	Greenhouse emissions, air pollutants, and noise emissions during operation	Advanced technologies: Electric powertrain of SRT vehicle for zero greenhouse gases and local air emissions as well as noise level reduction.
Security (safety)	Same accident rate as private vehicles due to human error	Advanced technologies: Autonomous driving functions 4-wheel independent steering

4. Conclusions

This study aimed to demonstrate how the SRT vehicle has been designed to improve the PT service quality attributes of comfort, accessibility, information, security, and environment. The innovations implemented in the SRT vehicle are mainly in two folds: advanced vehicle technologies including autonomous driving functions and electric powertrain, and application of Universal Design Principles in public transportation systems. The autonomous functions of the SRT vehicle are expected to improve safety, comfort, accessibility, and on-time performance of the system while the electric powertrain reduces the adverse environmental effects of the system including greenhouse gas and air pollutant emissions during operations as well as noise levels at stops and operating at low speeds.

The SRT vehicles and stations are designed according to the Universal Design principles, meaning that the features of the platform and interior design of the vehicles will ensure a simple, intuitive and equitable use to people with different abilities. It will include a perceptible information system and will not require extensive physical effort. Possible unintended actions of users will be identified at an early stage to minimize their consequences and finally, the dimensions of the platforms and vehicles will be adapted to users with different body sizes and postures.

Thus, the application of Universal Design principles along with the advanced vehicle technologies in the design of SRT supports the improvement of Service Quality thanks to a better accessibility, comfort as well as information provided to the passengers. The SRT system also integrates the Universal Design with advanced technologies in an early stage of its conception and development in order to ensure that infrastructure requirements are aligned with the proposed improvements. Zając (*21*) proposes the implementation of effective public consultations of planned actions directly with stakeholders to ensure public support from the beginning of the design process. Hence, participatory design could be a solution for ensuring the early consideration of users' needs within the design process and promote user acceptance of advanced technologies. Hence integration of vehicle technologies with Universal Design Principles at the early stage of the public transportation vehicles may provide improved customer satisfaction and hence service quality.

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6. References

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