TECHNOLOGIES FOR PRECISION DOCKING

AT LEVEL-BOARDING PLATFORMS

FOR BUS RAPID TRANSIT SYSTEMS

USING LOW-FLOOR BUSES

A RESEARCH PAPER

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF URBAN AND REGIONAL PLANNING

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JULY 2017
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Acronyms/Abbreviations

ADA – Americans with Disabilities Act of 1990
APTS – Advanced Public Transport Systems
BRT – Bus Rapid Transit
California PATH Program – California Partners for Advanced Transit and Highways
Community Transit – Transit Agency for Snohomish County, WA
CTfastrak – A regional BRT line operated by CTtransit
CTtransit – Transit agency for metropolitan areas of Connecticut
CTA – Chicago Transit Authority (Transit agency for Chicago, IL)
DAS – Docking Assist System
EmX – Emerald Express (BRT line operated by LTD)
FTA – Federal Transit Administration
GCRTA – Greater Cleveland Regional Transit Authority (Transit agency for Cleveland, OH)
HMI – Human-Machine Interface
IndyGo – Indianapolis Public Transportation Corporation (Transit agency for Indianapolis, IN)
ITDP – Institute for Transportation and Development Policy
KRRI – Korean Railroad Research Institute
Loop Link – BRT line operated by CTA
LRT – Light Rail Transit
LTD – Lane Transit District (Transit agency for Eugene, OR)
MARTA – Mécanique Aviation Traction
MAX – Metropolitan Area Express (BRT line operated by RTCSNV)
Metro Transit – Transit agency for Minneapolis-Saint Paul, MN
NACTO – National Association of City Transportation Officials
OmniTrans – San Bernardino County Public Transit (Transit agency for San Bernardino, CA)
Red Line – BRT line operated by Metro Transit
The Rapid – Interurban Transit Partnership (Transit agency for Grand Rapids, MI)
RTCSNV – Regional Transportation Commission of Southern Nevada (Transit agency for Las Vegas, NV)
sbX – Green Line (BRT line operated by OmniTrans)
Swift Blue Line – BRT line operated by Community Transit
TCAR – Transports en Commun de l’Agglomération Rouennaise (Transit agency for Rouen, France)
TCRP – Transit Cooperative Research Program
TEOR – Transport Est-Ouest Rouennais (BRT system operated by TCAR)
Introduction

Since the passage of the Americans with Disabilities Act of 1990 (ADA), buses have relied on bridge plates to allow equal access to passengers with mobility issues.\(^1\) However, by limiting the amount of space between the bus floor and the platform edge, delays that occur through bridge plate deployment can be eliminated. To achieve this, there are separate platform/vehicle floor alignment guidelines to which an agency must adhere.\(^2\) What would such an adherence mean for a Bus Rapid Transit (BRT) system’s performance? If BRT systems are to truly perform comparably to Light Rail Transit (LRT) systems, then this if must no longer be a question. Obtainment of ADA compliant gaps without the use of a bridge plate should not only be considered, but strived for and achieved. This requires a mitigation of both the vertical and the horizontal gap between the bus floor and the platform edge.

Before considering the horizontal gap, the vertical gap must be addressed. To avoid the delay from kneeling a bus, BRT systems utilize platform-level boarding. According to the Institute for Transportation and Development Policy (ITDP), platform-level boarding occurs when the station platform is the same height as the bus floor, regardless of height chosen.\(^3\) (ITDP, 2014) Once this vertical gap is minimized, the horizontal gap is addressed through the use of precision docking technologies. These are technologies that consistently and reliably reduce the horizontal gap between the bus floor and the station platform when docking. The combination of platform-level boarding and precision docking significantly reduces dwell time, or the time that a bus spends at a station, by minimizing the time passengers spend both boarding and alighting. As BRT systems continue to grow and are developed

\(^1\) The use of these ramps is outlined in ADA regulation 49 C.F.R. Part 38.23 as “All vehicles covered by this subpart shall provide a level-change mechanism or boarding device (e.g., lift or ramp)...”

\(^2\) Outlined in ADA regulation 49 C.F.R. Part 38.53 (d) as “...vehicles shall be coordinated with the boarding platform design such that the horizontal gap between each vehicle door at rest and the platform shall be no greater than 3 inches and the height of the vehicle floor shall be within plus or minus \(\frac{5}{16}\) inch of the platform height under all normal passenger load conditions.”

\(^3\) It is important not to confuse platform-level boarding with near-level boarding. The former creates a vertical gap that eliminates the need to step up into the bus, while the later leaves a small vertical gap that requires a step. (APTA, 2010)
as viable and equitable alternatives to LRT systems, compliance with this ADA regulation through gap mitigation and platform-level boarding is a necessity.

At this time, there does not exist a comprehensive evaluation of the existing technologies available in order to mitigate the size of this horizontal gap. Although guides have been developed, they often times are either too broad in scope or too limited in their coverage of the technologies. For instance, the now 14 year-old Transit Cooperative Research Program’s (TCRP) Report 90 gives a fair assessment of optical guidance, O’Bahn-type systems\(^4\), and early magnetic guidance systems, but lacks information on mechanical systems as discussed in this report. (TCRP, 2003) Meanwhile, the National Association of City Transportation Officials’ (NACTO) Transit Street Design Guide and the Institute for Transportation and Development Policy’s (ITDP) BRT Planning Guide and BRT Standard are all useful guides that recognize precision docking as an important aspect to a BRT system but fail to present sufficient information to make an informed decision on a specific technology. (ITDP, June, 2007)(ITDP, 2016)(NACTO, 2016) This leaves transit officials, planners, and managers spending unnecessary time and/or money seeking information independently or enlisting a consultant to prepare a comprehensive report specifically for their system. Therefore, this report has been created as a resource to provide assistance to designers, planners, officials, managers, or consultants who are seeking information on the feasibility of common level boarding technologies within their system, thereby saving both time and money.

Transit agencies worldwide have primarily implemented one of five technologies for precision docking which are categorized here as either mechanical or electronic. The two electronic systems are Optical Guidance and Magnetic Guidance. The three mechanical guidance systems are the Guide Wheel, Guide Strips, and the Kassel Kerb. This paper will address the performance expectations, cost, and

\(^{4}\) In reading Report 90, it is important to note that it refers to the O’Bahn curb-guided busways as mechanical guidance systems. Although the same terminology is used in this report, they are not the same technologies.
advantages and disadvantages of each technology. In addition, it will include suggestions for operator training and supplemental technologies to be used in conjunction primarily with the mechanical guidance technologies. A brief overview of the topics covered in this paper is included in Table 1 for use as a synopsis of this report for policy makers and transit professionals. It is important to note that the analysis found in this paper focuses solely on the expectations as they relate to low-floor buses. Although these technologies could also be used for BRT systems using high-floor buses, it would be wise to seek further information on potential strategies within those systems.
Table 1: Comparison of the Five Most Common Precision Docking Technologies.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cost</th>
<th>Gap Distance</th>
<th>Pros</th>
<th>Cons</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guide Wheel</td>
<td>$1,650 per arm, 1 - 2 arms per vehicle. No station cost.</td>
<td>4-8”, depending on approach pattern.</td>
<td>Consistent gap on curved approaches. Positive response from operators.</td>
<td>Concerns with vehicle insurance. System interoperability concerns.</td>
<td><img src="image" alt="Guide Wheel" /></td>
</tr>
<tr>
<td>Kassel Kerb</td>
<td>$193 per meter. $3,906 for 60' station face. No vehicle cost.</td>
<td>2-6”, depending on approach pattern. 1.97” with minimum 164’ straight approach.</td>
<td>Extensive use for 7” curb in Europe (Kassel Kerb Plus is less common). Good for system interoperability.</td>
<td>Not ideal for curved approaches. Increased concern of lug nut and/or fender damage.</td>
<td><img src="image" alt="Kassel Kerb" /></td>
</tr>
<tr>
<td>Guide Strip</td>
<td>$25 per linear foot. $1,500 for 60’ station face. No vehicle cost.</td>
<td>2-10”, depending on approach pattern. 3” with straight approach.</td>
<td>Becoming more popular in the US. Good for system interoperability.</td>
<td>Not ideal for curved approaches.</td>
<td><img src="image" alt="Guide Strip" /></td>
</tr>
<tr>
<td>Magnetic Guidance</td>
<td>$100k per vehicle and $10k - $20k per lane mile. No station cost.</td>
<td>Within 0.76” of target gap.</td>
<td>Ideal for curved approaches. Works well in all weather conditions. Positive response from operators.</td>
<td>Jerkiness can reduce rider comfort. System interoperability concerns.</td>
<td><img src="image" alt="Magnetic Guidance" /></td>
</tr>
<tr>
<td>Optical Guidance</td>
<td>$53k in per vehicle, $117k for technical integration, $48k for a calibration track. No station cost.</td>
<td>1.97” gap with a minimum 65’ straight approach.</td>
<td>Optimal docking 99.99% of time after phasing-in period. Initial failure rate of $0.1%.</td>
<td>Phasing-in period of several years. New buses cause a slight increase in failure rate. Poor performance in snow, arid climates, or glare from wet roads. System interoperability concerns.</td>
<td><img src="image" alt="Optical Guidance" /></td>
</tr>
</tbody>
</table>

5 All information for the Guide Wheel came from the following sources: California PATH Program, November 2007; Henke et al, June 2006; HNTB Corporation, September 2016; and FTA, March 2011.
6 See “Appendix 3 – System Interoperability Concerns.”
7 All information for the Kassel Kerb came from the following sources: Profilbeton; Brett Landscaping and Products, November 2014; George Lines Civils and Landscape Merchants, n.d.; Henke et al, June 2006; HNTB Corporation, September 2016; Melvin Cabang; Nathan Goldberg; and Andrew Swanepoel.
8 The cost for the Kassel Kerb is difficult to determine as it is not produced in the US and agencies in the US utilizing a comparable technology have poured the curb themselves.
9 All information for the Guide Strip came from the following sources: Polymer Industries; HNTB Corporation, September 2016; FTA, March 2011; and Conrad Venema.
11 All information for Optical Guidance came from the following sources: Phillips, 2006; California PATH Program, November 2007; COWI-SYSTRA, May 2014; Henke et al, June 2006; HNTB Corporation, September 2016; Kontron; and Siemens, December 2014.
The above table compares the five precision docking technologies analyzed in this paper using costs, gap distance, and their pros and cons for criteria. In terms of cost, the technologies can be generally divided into high cost and low cost, with the two electronic guidance systems considered high cost and the three mechanical guidance systems considered low cost. For gap distance, only the guide wheel was unable to produce a gap compliant with ADA guidelines and therefore is still required to use a bridge plate at times. Pros and cons can be considered together, first with system interoperability becoming a concern with the two electronic guidance systems and the guide wheel. For the electronic systems, this results from financial concerns due to the need to install the technology on non-BRT buses. For the guide wheel, this is a result of operating concerns of any buses when off the BRT line.\(^{12}\) As station treatments, neither the Kassel Kerb nor the guide strip have interoperability concerns. However, appropriate station approach becomes a major issue for these two technologies as they both require a significant straight line approach in order to perform effectively.

Overall, if finances are not a concern and the area experiences nice weather nearly all year long, an optical guidance has shown the ability to produce a quality experience. A magnetic guidance system also shows promise for a quality experience and has not seen the same difficulties with weather. Additionally, if there are expectations that the system ridership will expand beyond the desired capacity in the foreseeable future, a magnetic guidance system can support platooning\(^{13}\). (California PATH Program, January 2009) If financial issues are a concern, then both the Kassel Kerb and guide strips offer adequate precision docking capabilities. However, as they require straight approaches, space limitations may create significant problems. In this case, the guide wheel can offer a reliably small gap for able bodied passengers even with the required curved approaches. A bridge plate would still be required for

\(^{12}\) See “Appendix 3 – System Interoperability Concerns” for further discussion.

\(^{13}\) Platooning occurs when vehicles travel as a single unit. In the case of BRT, this would look and act similar to a multi-car train set commonly seen on LRT systems.
passengers with mobility constraints when using the guide wheel, but there exists specially built ramps which help to reduce the dwell time required by their use. So regardless of what your system requires, there is a method to produce a precise, satisfactory docking experience.

**Literature Review**

This paper exists as a comprehensive resource for decision makers on the primary technologies used for precision docking at level boarding platforms along BRT corridors utilizing low-floor buses. It assesses the cost, performance, and advantages and disadvantages of five current precision docking technologies. However, this paper does not contain definitive answers as to what is the “best” or “worst” technology, as such a determination is impossible given the wide range of project expectations, needs, and budgets. Instead, this report will allow decision makers to formulate an informed decision on what technology best fits the needs of their system.

First, it’s important to recognize that although quality BRT guides do exist, they lack a comprehensive focus on precision docking technologies. For instance, the National Association of City Transportation Officials’ (NACTO) *Transit Street Design Guide*, the Institute for Transportation and Development Policy’s (ITDP) *BRT Planning Guide* and their *BRT Standard*, and the Transit Cooperative Research Program’s (TCRP) *Report 90* all fail to provide adequate information for selecting a current level boarding technology. (ITDP, June, 2007)(ITDP, 2016)(NACTO, 2016)(TCRP, 2003) Although *Report 90* gives a fair assessment of early magnetic guidance and optical guidance technologies, due in part to the age of the document it does not cover several current advancements in the technologies covered in this report. The NACTO and ITDP guides all present a broad scope that attempts to cover all aspects of a BRT system. Although they are well developed guides, perhaps due to their broad scope, they present too little information to make an informed decision on the appropriateness of a given precision docking
technology. This document instead focuses on a narrower question asked by transit officials: What precision docking technology should be utilized on the system I’m building?

Just this question was asked by the Indianapolis Public Transportation Corporation for their proposed BRT system and was where the need of this report was determined. It was found that although information was generally available on the different technologies that could be used, it was scattered and lacked an accessible location where all of this information could be found. And as more and more agencies in America begin to consider the development of BRT systems, such accessibility is necessary. The collection of literature here addresses the expected cost, performance, and advantages and disadvantages of each technology. As adequate literature on all of these topics was not available for each technology, communication with industry professionals was sought to fill in any gaps in the research.

The most extensive research and analysis of precision docking technologies in the United States has come from the FTA and the California Partners for Advanced Transit and Highways (PATH) program. To start, the magnetic guidance system reviewed in this report was developed by the California PATH Program and retrofitted to a 60’ BRT bus owned by the Land Transit District (LTD) and placed into revenue service along their BRT line, the Emerald Express (EmX). Its performance was assessed between June 2013 and December 2014 by the FTA. (FTA, January, 2016) In a separate report, the FTA evaluated the performance of the current technology used by LTD along their EmX line, the guide strip. It was a comparison report between this guide strip and the guide wheel, which is the current technology used along the Greater Cleveland Regional Transit Authority’s (GCRTA) BRT line, the Healthline. (FTA, March, 2011) However, the guide strip used by LTD is not meant for precision docking but to protect the buses and stations from damage due to collisions. Therefore, that FTA report is used primarily as a reference for guide wheel performance expectations and the experiences of the Interurban Transit Partnership.
(The Rapid) in Grand Rapids, MI along their BRT line, the Silver Line, are considered more relevant to the potential performance of the guide strip as it was the agency’s aim to use the technology specifically for precision docking. As there are no papers analyzing the performance of guide strip usage along the Silver Line, information was gathered directly through communications with officials from the agency. The successes of the optical guidance system used in Rouen, France has been referenced in several reports. (COWI-SYSTRA, May 2014)(Henke, Kantor, and Moscoe, June 2006)(California PATH Program, November 2007)(California PATH Program, January 2009)(TCRP, 2003) A consortium consultant firm, COWI-SYSTRA, analyzed the performance for gap distance, ridership response, and costs associated for the technology. (COWI-SYSTRA, May 2014) The problems inherent with the technology have been noted in several reports and most prevalently through the reports citing the termination of the technology’s use in Las Vegas, NV due to roadway maintenance costs and issues with the climate. (Henke, Kantor, and Moscoe, June 2006)(Phillips, 2006)(HNTB Corporation, September, 2016)(UniServices Ltd., July 13, 2016) The Kassel Kerb is widely used in Europe for gap mitigation along local bus routes. (HNTB Corporation, September 2016) Although primarily used for these lower curbs, it has been used for precision docking in some American cities such as Las Vegas, NV, although not initially as the primary technology, and San Bernardino, CA, although more for damage prevention. Due to Buy America standards, their curbs were self-poured, leaving the potential for wide variability in performance measurements and expectations. As the level-boarding style of this curb design is simply a standard height Kassel Kerb with a recessed edge\textsuperscript{14} and literature specifically on the performance of level-boarding height Kassel Kerbs was not available, performance measurements and estimated costs are derived through manufacture specifications for standard curb heights. (Brett Landscaping and Building Products, November 2014)(George Lines Civils and Landscape Merchants, n.d.)(Caiaffa, M

\textsuperscript{14} See “Kassel Kerb” section of this report for more information.
Tyler, N, January 1, 1999) (Profilbeton) Additionally, communication with agency officials from the San Bernardino County Public Transit (OmniTrans) and the Regional Transportation Commission of Southern Nevada (RTCSNV) where used for comparison.

The last section of this report focuses on supplemental technologies that can be used primarily in conjunction with the mechanical guidance technologies to help decrease the horizontal gap and increase operator comfort and consistency. There is very little literature on these technologies and they are never the focus of the papers in which they appear, although some information on their use was featured in a 1999 presentation titled Design of Fully Accessible Bus Stops Infrastructure: Elements for Buses and Drivers, and a March 2011 FTA report titled An Evaluation of the Cleveland Healthline Mechanical Guide Wheel. Regardless, most of the information on these topics was acquired through communication with industry professionals. Despite this dearth of readily accessible information, these technologies can lead to dramatic improvements in performance as was seen along OmniTrans sbX Green Line\(^\text{15}\). Much of this ties into increased comfort level of operators. (Melvin Cabang, personal communication, January 22, 2016) (Dr. Floun’say Caver, personal communication, February 29, 2016)

Therefore, these technologies are intimately tied to operator training. And due to the lack of information available on supplemental technologies, it is certain that the options presented in this report should not be taken as an exhaustive list\(^\text{16}\).

Finally, there are technologies that can be used for precision docking but are not covered in this report. This is because this report focuses on technologies whose primary purpose is precision docking. Therefore, unless this is the case and a technology has been used and/or tested as such, it was not

\(^{15}\) Their use of spot mirrors and curb feelers is more thoroughly discussed in the “Supplemental Technologies for Mechanical Docking Technologies and Driver Training” section of this report.

\(^{16}\) In fact, information on the use of spot mirrors, Carey Fingers, and curb feelers was collected entirely by word of mouth. See the “Supplemental Technologies for Mechanical Docking Technologies and Driver Training” section of this report for more information.
analyzed in this report. GPS guidance is a technology which has yet to have been tested specifically for precision docking. It has been tested by Metro Transit in Minneapolis, MN for the operation a 9.5’ wide coach on a 10’ wide shoulder, particularly under low visibility conditions, and the California Partners in Advanced Transit and Highways (PATH) program has performed tests to improve GPS technology for such purposes. (California PATH Program, 2009)(Pessaro, 2013) However, as the tests were not in revenue service, and therefore not ready for implementation as a precision docking technology, it was considered outside of the scope of this paper. There are also O’Bahn systems in places such as Leeds, United Kingdom and Adelaide, Australia. These systems rely on guide wheels to guide the buses along a concrete track and have not been considered in this report as they are primarily a guideway system and not a precision docking technology. However, it is important to note that it is from these systems that the Greater Cleveland Regional Transit Authority (GCRTA) conceived the idea of using a guide wheel purely for precision docking along the Healthline. (California PATH Program, March 2007) Similar to the O’Bahn systems, there are the Translohr rail-guided buses seen primarily in France. (TRCP, 2003) These were considered outside of the scope of this paper as they are primarily a guideway technology and not a precision docking technology. Lastly, there does exist comparable technologies to the Kassel Kerb in the Marshall Bus Stop Kerb and the Charcon Access Kerb. However, due to extreme similarities in the technologies, the prevalence of self-poured curbs in the United States, and the popularity of the Kassel Kerb, this report focused singularly on the Kassel Kerb. Its analysis is likely comparable to the similar technologies previously mentioned.

**Magnetic Guidance**

The magnetic guidance technology reviewed in this report was developed by the California Partners for Advanced Transit and Highways (PATH) and as completion of this report (June 2017) it is in the process of being commercialized. This technology uses five (5) key components by which to control
the lateral, or side-to-side, position of a vehicle while an operator maintains control of the vehicle’s speed and braking. A steering actuator physically controls the steering wheel during automated control without affecting performance while the system is disabled. Magnetic sensors are placed at the front and the rear of the bus to constantly measure its lateral position with respect to magnetic markers embedded in the roadway (see Figure 2). A Differential Global Positioning System/Inertial Navigation System (DGPS/INS) is used as a secondary sensing mechanism and utilizes a yaw rate gyro to measure the lateral change of the vehicle. These mechanisms continuously calculate the position of the bus and interact via control computers to determine the accuracy of its location and make needed adjustments to keep the bus on path. Finally, a Human-Machine Interface (HMI), which are a series of buzzers, indicators, switches, and buttons, relay relevant information to the driver. A visual breakdown of this technology can be seen in Figure 1.

Figure 1: Magnetic Guidance Components. (Source: FTA, January 2016)
There does exist a separate magnetic guidance technology that, due to its history, needs to be addressed to avoid potential confusion. It was developed by Frog Navigations and introduced as part of the Phileas Bus designed by the Advanced Public Transport Systems BV (APTS) of Helmond, The Netherlands. This technology was developed independently from the PATH system and they are not interchangeable. The APTS technology was implemented in Eindhoven, The Netherlands; Istanbul, Turkey; and Douai, France and has since been discontinued due to its failure to meet increasing European safety standards, a lack of payments due to these failures, and the subsequent bankruptcy of APTS in 2014. (Erik Van Hal, personal Communications, December 23, 2016)(Van Der Leegte Groep, 2014)(Wei Bin Zhang, personal Communications, May 4, 2016) However, this technology has been purchased by the Korean Railroad Research Institute (KRRI), presumably for further development in South Korea as a part of their Bimodal Tram project. (Wei Bin Zhang, personal Communication, May 4, 2016) Therefore, although its performance is not discussed further due to previous struggles, there is the potential that this technology could reappear in the future.

Figure 2: Magnet in Road. (Source: Graham Carey)
**Performance**

The magnetic guidance technology developed by PATH has been in development and testing since 1988. In this time, the technology has shown reliability in some of the most extreme weather conditions. As in 1998 when it was installed as a guidance system on a snowplow used along the Donner Pass, in which the magnets were able to remain in place and functional through several freeze/thaw cycles each year. (California PATH Program, January 2009) Additionally, this technology was retrofitted to two 40’ New Flyer buses in 2003. In out-of-service demonstrations, therefore without customers, these buses were able to achieve a consistent horizontal gap of 2 cm (0.79”) in San Diego and Washington DC. (2009)

A 2016 FTA study reported on the performance of the PATH magnetic guidance system on a 60’ New Flyer bus owned by the Lane Transit District (LTD) in Eugene, OR. In in-service testing, therefore with customers, along the Emerald Express (EmX) line, LTD’s BRT line, a target gap of 4 cm (1.57”) between the vehicle floor and the guide strips previously installed at the target stations was sought. These tests showed a consistently smaller horizontal gap with the magnetic guidance system enabled than when it was disabled. While enabled, the maximum distance from the target gap was 1.94 cm (0.76”), compared to a maximum distance when disabled of 11.08 cm (4.36”). (FTA, January 2016)

**Cost**

As the PATH system has yet to be commercialized, the cost of the technology can only be estimated. These estimates suggest the cost of retrofitting a bus will be approximately $100,000 per bus. Additionally, installation of the magnets within the roadway would cost between $10,000 and $20,000 per lane mile. The majority of the cost related to lane miles is due to the high precision of surveying needed during installation of the magnets. (Wei Bin Z., personal communication, April 8, 2016)
Advantages/Disadvantages

Surveys from the same 2016 FTA report indicated that bus operator perception of the technology was overwhelmingly positive. Most significantly, operators’ responses indicated a reduced level of stress and a greater level of safety as they were better able to focus on platform and rider activity while approaching a station. Further, the consistent performance of the technology led to an elimination of platform collisions while the technology was enabled, saving money in maintenance costs. The operators did indicate an initial hesitancy to trust the system and mirrored passenger responses in that the system felt “jerky” during lane guidance, however, this jerkiness was expressed as an issue during lane guidance and not during precision docking. (FTA, January 2016) See Table 2 in Appendix 1 for operator responses to the magnetic guidance system.

Optical Guidance

Optical guidance systems utilize a camera positioned either behind or above the windscreen of a bus to recognize a particular paint on the roadway and uses this as a means to control lateral movement, relying on an operator to control speed and braking. (COWI-SYSTRA, May 2014)(TCRP, 2003) This technology was developed by MARTA17, or Mécanique Aviation Traction, and subsequently purchased by Siemens, who is currently the only company providing the technology. (California PATH Program, November 2007)(COWI-SYSTRA, May 2014)

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17 There is no connection here between the Mécanique Aviation Traction and the Metropolitan Atlanta Rapid Transit Authority in Atlanta, GA, both who use the acronym MARTA.
Rouen, France made the decision to implement an optical guidance system in 2001 with the intent of creating a BRT system, named Transport Est-Ouest Rouennais (TEOR) and operated by Transports en Commun de l'Agglomération Rouennaise (TCAR), that would achieve the same satisfaction rates as their Light Rail Transit (LRT) system. The optical guidance technology used along this BRT system achieves an optimal approach 99.9% of the time. In order to achieve this optimal approach, it requires a 20 m (65.62’) straight alignment approaching each station. Optical guidance systems have a unique quality in that they improve with time and require a phasing-in period of a few years to reach optimum performance. This should not be taken to mean that the vehicles perform poorly during this phasing-in period. In Rouen, the initial failure rate in 2002, the year of implementation, was 1.37 per 1000 station approaches (99.863% success rate) and leveled out to 0.195 failures per 1000 station approaches (99.981% success rate) by 2006. (COWI-SYSTRA, May 2014) Although “failure” was not specifically defined in the COWI-SYSTRA article, Siemens rates the performance of their Optiguide/Optiboard optical guidance system, which is the system used in Rouen, at maintaining a 50 mm (1.97”) gap between bus and platform. This suggests that a “failure” would be when a gap greater than 50 mm (1.97”) occurs. (Kontron)(Siemens, December 2014)(Rouen, France Brief: TEAR Optically Guided Bus) Also note that the
introduction of additional buses causes an increase in the failure rate. The arrival of new vehicles in Rouen in 2007 increased the failure rate to 0.425 per 1000 station approaches (99.958% success rate) before ultimately leveling out to 0.15 faults per 1000 station approaches (99.985% success rate) by 2011. (COWI-SYSTRA, May 2014)

**Cost**

The cost of this technology is not precise due to the low number of cases of implementation. However, Siemens, who is the manufacturer of the technology, projects that it would cost between 2% and 5% of a new vehicle and is likely around 50,000 € (~$53,000) per vehicle to retrofit. (Siemens, December 2014) (COWI-SYSTRA, May 2014) The Regional Transportation Commission of Southern Nevada (RTCSNV) in Las Vegas, NV implemented CIVIS along their Metropolitan Area Express (MAX) BRT line at a cost of approximately $100,000 per bus to install the technology. (Rouen, France Brief: TEAR Optically Guided Bus) Technical studies for integration at each station would amount to approximately 110,000 € (~$116,600) for a given line and involves the construction of a calibration track at 45,000 € (~$47,700). Operationally, Rouen spent 826,000 € (~$875,600) in 2011 with a fleet of 66 equipped buses. (COWI-SYSTRA, May 2014) A breakdown of these costs can be seen in Table 3 in Appendix 1.

**Advantages/Disadvantages**

This technology has shown performance difficulties in poor weather conditions. RTCSNV’s now discounted MAX line discontinued the use of this technology after experiencing disruption problems due to dirt and oil build up from a lack of rain in the desert climate. (Henke, Kantor, and Moscoe, June 2006) UniServices Ltd., July 13, 2016) A report from the California PATH Program at UC Berkeley mentioned the absence of snow in Rouen as a factor in its success and stated that, “[t]he system sometimes cannot engage when the sun angle is low and pointed toward the bus, as well as in the special condition of glare
off wet pavement...There are only a few snowy days per year in Rouen, and drivers are advised to turn off the system when it is snowing.” (California PATH Program, pg. 9, January 2009)

Surveys of the bus operators in Rouen were found to be generally favorable towards the optical guidance system. They found the system to be more convenient than doing the docking themselves, that it relieved them of some of the workload so that they could interact more with the passengers, and that it helped to reduce their level of stress. (California PATH Program, November 2007) This also helped lead to an increase in safety as system operators reported that they could, “...devote more attention to their surroundings, rather than low-level vehicle maneuvering.” (pg. 8, 2007) Ultimately, the use of optical guidance technology was considered to have achieved the goal set forth in 2001 as passengers rated the satisfaction of their experience comparable to that of the LRT system also in Rouen. (2007)

**Guide Wheel**

The guide wheel is a small mechanical wheel attached to the steering axle of a bus. These are used for guidance along guided busways in Leeds, UK; Essen, Germany; and Adelaide, Australia. The Greater Cleveland Regional Transit Authority (GCRTA) in Cleveland, OH uses guide wheels solely for precision docking along their BRT system, known as the Healthline. They are attached to both sides of the bus as passengers are able to board on either side depending on the location of the stations. (California PATH Program, January 2009)(Phillips, 2006)(FTA, March 2011)
Performance

According to a 2011 FTA report, performance along the route saw an average gap of 8” between the bus door and the platform on straight approaches and 6.5” on curved approaches\textsuperscript{18}. (FTA, March 2011) These performance measures have not changed since the 2011 report. (Dr. Floun’say Caver, personal communication, February 29, 2016) Although this does not achieve the gap set forth in ADA regulation, these gaps are manageable by able-bodied riders and a bridge plate is utilized to bridge the gap for passengers with mobility challenges.

Cost

The GCRTA spent $3,700 per vehicle, 2 arms per vehicle at $1,650 per arm, for the installation of the guide wheels. In terms of maintenance costs, GCRTA spent $15,060 in 2009 to repair broken docking arms for their entire BRT fleet, which covered over 723,000 revenue miles. (FTA, March 2011) The GCRTA has reported that this cost has since declined due to use of higher quality metal for the arms and alterations to driver training which has reduced the frequency of arms breakage. Specifics on how much

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\textsuperscript{18} Gap measurements were made from the second door on the left side of the bus, at the forward most side of the doorway. (FTA, March 2011)
this cost has declined were not available. (Dr. Floun’say Caver, personal communication, February 29, 2016)

**Advantage/Disadvantages**

A survey of driver responses to the use of the mechanical arms showed that 80% of Cleveland operators agreed or strongly agreed that the guide wheel helped them dock more quickly and precisely, that it was easy to use, and that they would recommend it to other transit agencies. 77% agreed or strongly agreed that it made docking less stressful. (FTA, March 2011)

When installing the guide wheel, GCRTA was required by New Flyer, the manufacturer of the BRT buses in their fleet, to void the warranty for the vehicles on which the guide wheels were installed. GCRTA also had concerns that the arms could cause damage to the axle, so they are designed to break off prior to such an occurrence. This likely led to the issue of frequent breaking early on and resulted in the maintenance costs seen in the 2011 FTA report. This frequent breakage also created reliability concerns as a bus must be removed from service to replace the broken guide wheel, although it remained otherwise still functional. (Dr. Floun’say Caver, personal communication, February 29, 2016)

**Kassel Kerb**

The Kassel Kerb is a specially designed curb originally developed in Kassel, Germany. It is a curb with a beveled edge that bus wheels can safely rub against as they approach a station, leading to a reduction of the gap between the bus floor and the platform. This technology is widely used across Europe for standard height curbs, with companies such as Brett Landscaping and Paving manufacturing in heights of 160mm (6.3”) and 180mm (7.09”). (HNTB Corporation, September 2016)(Brett Landscaping and Building Products, November 2014) Although these curb heights are not adequate for level
boarding, their performance is comparable to Kassel Kerb Plus®-style curbs. These heightened curb designs increase their heights by using a recessed edge and raising the curb to the desired height, thus allowing for level boarding (see Figure 5). The recessed edge is a necessary element for level boarding to avoid damage to lug nuts or fender flares while still being of sufficient height.¹⁹ At this time (2017), there are no manufacturers of this product in the United States, which is important if Buy America standards apply to a transit project. Often times, this leads to a self-pouring of the curbs, as was done by San Bernardino County Public Transit (Omnitrans) in San Bernardino, CA along the sbX Green Line and the Regional Transportation Commission of Southern Nevada’s (RTCSNV) former Metropolitan Area Express (MAX) line in Las Vegas, NV. (Melvin Cabang, personal communication, January 22, 2016)(Nathan Goldberg, personal communication, March 3, 2016) Additionally, the Champaign-Urbana Mass Transit District is planning on using a self-poured version of the technology for a proposed BRT corridor in the city using the schematics seen in Figure 7. (HNTB Corporation, September 2016)

![Figure 5: Kassel Kerb in Kassel, Germany (Source: Graham Carey)](image)

¹⁹ See “Appendix 2 – Lug Nut/Fender Flare Variance” for a further discussion on this topic.
Performance

According to Brett Landscaping, Kassel Kerbs provide for a gap of 50 mm (1.97”) or less. To achieve this desired gap, a linear approach of no less than 50 m (164.04’) is required. (Brett Landscaping and Building Products, November 2014) In San Bernardino, the curbs are used primarily to avoid collision with the platform and were self-poured due to Buy America restrictions. Utilizing supplemental technologies\textsuperscript{20} along with the curb, Omnitrans achieves a regular gap of 6”. (Melvin Cabang, personal communication, January 22, 2016) Therefore, a bridge plate is still required to cover the gap between the bus and the platform for riders in wheelchairs. Additionally, as no recessed edge was used at their stations, lug nuts are known to cause damage to the yellow dome pavers used as a warning strip for passengers. In Las Vegas, RTCSNV implemented sloped curves along their MAX BRT route, although it was not to be the primary precision docking technology at the time of implementation (as of February 21, 2016, MAX had been discontinued). In order to prevent lug nut damage to their vehicles, each was equipped with wheel covers. These covers did sustain minor damage from occasional scraping against the curb. Contractors for RTCSNV, Keolis and MV Transportation, reported that the MAX vehicles were able to achieve an average gap of 3-4” using the sloped curves (this was after the discontinuation of the optical guidance system). (Nathan Goldberg, personal communication, March 3, 2016)

Figure 6: Self-Poured Kassel Kerbs in San Bernardino, CA. (Source: Omnitrans via Melvin Cabang)

\textsuperscript{20} See the “Supplemental Technologies” section for more information.
Cost

Currently in the United States, Buy America Standards for federal projects limit the ability to purchase prefabricated Kassel Kerbs. Due to this, these curbs have been self-poured and the cost is not necessarily a line item that can be used for direct comparison. However, for comparison, the standard 1m (3.28’) long, 180 mm (6.3”) high Kassel Kerb is £149.50 (~$190). Therefore, a 60’ platform would cost approximately £3,017 (~$3,900) per face to install.21 (George Lines Civils and Landscape Merchants, n.d.) Due to the current need to self-pour these curbs in the US, these should only be viewed as rough estimates.

Figure 7: Potential Specs for Champaign-Urbana Mass Transit District’s Kassel Kerb-style curb. (Source: HNTB Corporation, September 2016)

Advantages/Disadvantages

When compared to standard curbs, this technology helps to reduce tire wear. MyCiTi in Cape Town, South Africa utilizes Kassel Kerbs for both their trunk and curb-side stations. Their primary reason was identified as the 40% reduction in tire wear as, “according to operators in other BRT systems, the

21 Calculated by assuming 18, 1m segments and one taper segment per end. Taper segments are recommended to bring the curb up to the appropriate height.
most expensive operating cost after fuel is the cost of replacing tyres.” (Andrew Swanepoel, personal communication, February 18, 2016) Although MyCiTi uses high-floor buses, tire wear reduction would be the same for low-floor buses.

As pointed to earlier, a significant concern with the Kassel Kerb is potential damage to both lug nuts and fender flares. Unless properly constructed, the curb has the potential to cause significant damage to both the vehicle and the station and lead to large, unexpected maintenance costs. Also, given the 50m (164.04’) minimum approach distance, Kassel Kerbs are not ideal corridors requiring curved approaches.

Guide Strip

Guide strips are typically a polyethylene strip used to guide buses along docking platforms. They assist in preventing collisions between the bus and the platform by allowing the tires to rub against the strip. Its use can vary depending on the desires of the transit agency implementing it. The primary function of guide strips by the Lane Transit District (LTD) in Eugene, OR along their BRT line, the Emerald Express (EmX), is primarily to prevent damage caused by contact between buses and stations. However, the Interurban Transit Partnership (The Rapid) in Grand Rapids, MI, uses the technology primarily for precision docking along their BRT line, the Sliver Line. Additionally, this technology is used along Metro Transit’s Red Line in the Minneapolis-Saint Paul, MN area, the Chicago Transit Authority’s (CTA) Loop Link in downtown Chicago, and along Community Transit’s Swift Blue Line in Snohomish County, WA. (HNTB Corporation, September 2016)
Performance

According to a 2011 FTA report, the guide strip used by LTD achieved an average gap of 8.5\textsuperscript{22} between the door and the platform with straight approaches and 9.75” with curved approaches (FTA, March 2011). Representative of LTD pointed out that operators have been able to decrease this gap but did not give specific figures except to say that it is rarely below 6”. (Mark Johnson, personal communication, February 22, 2016) Remember that LTD uses guide strips for damage control, not precision docking.

Along The Rapid’s Silver Line, a maximum gap of 3” has been consistently achieved. (Conrad Venema, personal communication, February 2, 2016)(HNTB Corporation, September 2016) Two factors have been attributed to leading to this performance: appropriate driver training and a focus on making approaches to stations as straight as possible. The 3” gap mentioned above is achieved at all but one station due to a left turn prior to docking. This results in the back door\textsuperscript{23} being unable to consistently obtain the 3” gap. However, in the first two years of operation of the Silver Line, deployment of a bridge plate, which are still installed in their Silver Line buses, has not been needed for accessibility needs.

(Conrad Venema, personal communication, July 19, 2016)

\textsuperscript{22} Gap measurements were made from the second door on the left side of the bus, at the forward most side of the doorway. (FTA, March 2011)

\textsuperscript{23} In this case, the back door is the second of two as The Rapid uses 40’ buses for the Silver Line.
**Cost**

LTD spent $2,500 per side per station at $25 per linear foot to install their guide strips (no data on lifecycle cost was available). In terms of maintenance costs, LTD spent $1,252 in 2009 to replace 6 tires damaged during pull out from stations, which covered 203,699 revenue miles. (FTA, March 2011).

**Advantages/Disadvantages**

Maintenance costs could be of issue with this technology, as seen with LTD. However, officials working with The Rapid made no mention of excessive damage to their tires during docking. A possible explanation here is that the more aggressive turns required during docking approaches in the LTD system may be a factor. Officials working with The Rapid did note an increased wear due to frequent rubbing against the guide strips. (Conrad Venema, personal communication, February 2, 2016)

Success with this technology requires careful attention to designing the approach to each station. In order to obtain the smallest horizontal gap distance, it is essential that the approaches be as straight as possible. The Rapid is able to achieve their gap due to their emphasis on straight line approaches. LTD lacked this option due to spatial limitations along their system, likely resulting in the increased gap found in the 2011 FTA study.

**Supplemental Technologies and Driver Training**

**Supplemental Technologies**

There are several supplemental technologies that can be used in conjunction primarily with the three mechanical precision docking technologies. None of these are required for adequate performance of the precision docking technologies, but as a means to increase performance and operator confidence. The performance of these supplemental technologies has not been independently measured. The cost
of these technologies can be considered minimal unless otherwise noted. Five supplemental technologies will be briefly covered here; Docking Assist Systems (DAS), guide stripes, curb feelers, spot mirrors, and Carey Fingers.

![Figure 9: Painted Blue Guide Stripe (left) and Driver Assist System (DAS) (right) used by GCRTA in Cleveland, OH. (Source: FTA, March 2011)](image)

In Cleveland, guide wheels are used in conjunction with a Driver Assist System (DAS) and a painted blue guide stripe on the road (see Figure 9). The DAS is an audible warning system that alerts operators by emitting four successive beeps when contact with the platform is imminent. The DAS used by GCRTA cost $4,929 ($216 for each sensor, $647 for the controller, and $150 for the speaker) for each bus. (FTA, March 2011) The blue guide stripe is simply a painted line that is aligned with the operator’s seat and used to visually guide the operator along a specific path. In Cleveland, it is repainted annually. In helping to guide an operator’s path, the blue guide stripe helps to prevent excessive “tail-swing” during pull-out from a station. Additionally, the blue guide stripe can help guide an operator into a station and prevent a larger than desired gap between the station platform and the rear doors, a problem that is more significant when using an articulated coach. Also, a painted line can help prevent

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24 Tail-swing occurs when a bus turns sharply in one direction and the tail of the bus breaks the linear plane on the opposite side of the bus. This can lead to unwanted contact between the tail of the bus and the station.
damage cause by contact between the joint of an articulated bus and the station, which can occur when turning too sharply during pull-out from a station.

Figure 10: Curb Feeler on Orange Line bus in Los Angeles County, CA. (Source: Carren Jao via Zocalo Public Square, July 2, 2012)

In San Bernardino, Kassel Kerbs are used to prevent buses from colliding with stations. Initially, the San Bernardino Express (SbX) line was seeing horizontal gaps of approximately one foot. In response, both curb feelers and an additional spot mirror were installed to increase driver confidence, as seen in Figures 10 and 11. (M. Cabang, personal communication, January 22, 2016) These additional measures have been pointed to as a reason for the reduction to the currently reported gap of approximately 6”.

Figure 11: Spot Mirror. (Source: Magnum Vehicle Solutions)
CTFastrak, a regional BRT line operated by Connecticut Transit (CTtransit) connecting Hartford, CT to New Britain, CT, uses a combination of guide strips and Carey Fingers. Carey Fingers are made of a polyurethane elastomer and can extend out from the platform up to 3.75”, see Figure 12. (G. Carey, personal communications, September 22, 2016) The main body of the Carey Fingers is constructed using a C-shaped piece of metal encased in the polyurethane. The fingers, also made of polyurethane, extended out and allow buses to rub against them without incurring damage or markings. Importantly, they are rigid enough to sustain the weight of wheelchairs. CTtransit places the Carey Fingers on the platform edge at the location of the doors. By doing so, the fingers can allow for a nearly imperceptible gap when docking, as seen in Figure 12. Although the Carey Fingers are considered here primarily for use with mechanical guidance technology, there’s no reason that this technology couldn’t successfully and usefully be implemented with either the mechanical or the electronic guidance systems.

![Carey Fingers](image)

**Figure 12:** Carey Fingers (Source: Graham Carey)
Driver Training

Driver training varies between agencies, but using precedents for certain technologies can prove beneficial. There can be several obstacles to overcome, including training operators to drive “into” a curb, completely let go of the steering wheel, and docking on the left side. None of these would be considered part of a typical bus operator training course.

At the Transports en Commun de l’Agglomération Rouennaise (TCAR) in Rouen, France, the BRT system, Transport Est-Ouest Rouennais (TEOR), uses an optical guidance system for precision docking. Before operating on the BRT lines, TOER operators have a five (5)-day training period to adjust to the new vehicle and guidance system, as well as to learn how to activate the signal preemption system. Both the TEOR drivers and the LRT drivers are required to drive a regular bus route for one week of each 12-week schedule period in order to ensure that they maintain their driving and docking skills. (California PATH Program, November 2007)

At the Greater Cleveland Regional Transit Authority (GCRTA) in Cleveland, all operators on the Healthline receive classroom and field training on the guide wheels for a minimum of two (2) days, one (1) full day and two (2) half days. Day 1 includes classroom instruction using the Bus Operators Handbook, familiarization on the BRT buses, driving the BRT buses on the WestPark Training Track, and driving on the Euclid Avenue HealthLine corridor with concentration on left-side docking. The two half days of instruction include more practice driving on the Euclid corridor and final assessments of the operator’s capabilities. If the instructors determine that additional driving time or practice is required, the length of the individuals training is extended to ensure safe driving practices are followed. (FTA, March 2011)
A representative of GCRTA pointed out that if operators are harshly reprimanded when they cause damage to the buses, they are more likely to be too cautious when approaching a station. (Dr. Floun’say Caver, personal communication, February 29, 2016) This causes issues in achievement of the desired gaps, especially when approaching on a curve. Therefore, at GCRTA, they do not immediately assume operator error when damage to a bus occurs while attempting to dock at a BRT station, which is not typical industry practice. Although such collisions are still investigated, operators are given the benefit of the doubt and only charged in serious cases which point clearly to operator error.

**Conclusion**

Bus Rapid Transit (BRT) systems are being implemented across the world, and increasingly in the United States, as a cost effective and a more rapidly developable alternative to Light Rail Transit (LRT) systems. Research points to LRT systems being too expensive when compared to bus systems, having schemes with poor financial performance, and planning timescales that are excessively long. (Hodgson et al, 2013) If BRT is truly comparable, then this may seem to suggest that BRT should be the preferred alternative in every situation. However, shortcomings exist with BRT systems when comparing them to LRT systems. Precision docking is more difficult, ridership comfort is reduced, and the vehicle capacity is lower. This report has shown that with appropriate care and consideration there exists technologies, or combinations of technologies, that can offer precision docking along BRT systems that is all but equivalent to LRT systems.

This paper has reviewed five of the most common and practical technologies for precision docking along with supplemental technologies that can be equip simultaneously with the mechanical guidance technologies to increase their effectiveness. Although it’s not a guarantee that any one

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25 Dr. Floun’say Caver, Hayden District Director for GCRTA, pointed to this as important consideration for obtaining the desired gap as operators are traditionally trained to avoid contact with curbs.
technology will meet all of the demands of every system, this paper should allow for an understanding of the strengths and weaknesses of each technology. Using this report, designers, planners, officials, managers, and consultants for BRT systems should be better able to select the technology that best fits the needs and requirements of their system. With the appropriate due diligence in corridor design, such as station approach, as well as the appropriate combination of supplemental technologies, any of the five technologies covered here can obtain a desirable gap. However, further considerations of system guideways, cost, interoperability, driver training, and other unique situations inherent in any major transportation project must be addressed to ensure that the chosen precision docking technology not only performs well at the stations, but allows for success away from the stations. Precision docking is only one of the numerous crucial factors that goes into the construction of a successful rapid transit corridor and system.
Appendix 1 – Additional Tables

Table 2: Operator Responses to Interaction with the Magnetic Guidance System. (Source: FTA, January 2016)

<table>
<thead>
<tr>
<th>Aspect of Precision Docking</th>
<th>Mean Score</th>
<th>No. of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering between stations</td>
<td>3.75</td>
<td>12</td>
</tr>
<tr>
<td>Minimal swaying of bus</td>
<td>3.33</td>
<td>12</td>
</tr>
<tr>
<td>Overall smoothness of ride</td>
<td>3.58</td>
<td>12</td>
</tr>
<tr>
<td>Speed of bus</td>
<td>4.42</td>
<td>12</td>
</tr>
<tr>
<td>Accuracy of aligning to station</td>
<td>4.91</td>
<td>11</td>
</tr>
<tr>
<td>Ease of boarding and alighting</td>
<td>4.92</td>
<td>12</td>
</tr>
<tr>
<td>Safety</td>
<td>4.73</td>
<td>11</td>
</tr>
<tr>
<td>Assistance to bus driver</td>
<td>4.60</td>
<td>10</td>
</tr>
</tbody>
</table>

Survey scale: 5 Very Good, 4 Good, 3 Fair, 2 Poor, 1 Very Poor, 0 Don’t Know. Mean score does not include 0 Don’t Know responses.

Table 3: Operational Cost of Optical Guidance System in 2011 in Rouen, France (Source: COWI-SYSTRA, May 2014)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Guidance system</strong></td>
<td></td>
</tr>
<tr>
<td>Inboard guidance system</td>
<td></td>
</tr>
<tr>
<td>+ steering system</td>
<td></td>
</tr>
<tr>
<td>+ motorization</td>
<td></td>
</tr>
<tr>
<td>+ lights control</td>
<td></td>
</tr>
<tr>
<td>+ access to vehicles</td>
<td></td>
</tr>
<tr>
<td>21,000 €</td>
<td>75 % taken into account by contract with Siemens, and 25 % related to curative maintenance</td>
</tr>
<tr>
<td><strong>Roadway Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>130,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Traffic Lights</strong></td>
<td>Specific to local context (many traffic lights to replace)</td>
</tr>
<tr>
<td>355,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Roadway Marking Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>68,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Stations’ Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>83,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Roadway Clean-up</strong></td>
<td></td>
</tr>
<tr>
<td>52,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Systems</strong></td>
<td></td>
</tr>
<tr>
<td>185,000 €</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td>826,000 €</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix 2 – Lug Nut/Fender Flare Variance

**Table 4:** Lug Nut and Fender Flare Measurements from the Indianapolis Public Transportation Corporation Bus Fleet, April 2016 (Source: Cody J. Hedges)

<table>
<thead>
<tr>
<th>Manufacturer (series)</th>
<th>Model Year</th>
<th>Bus Length</th>
<th>Lug Nut Protrusion</th>
<th>Fender Flare Protrusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Flyer (0201-16)</td>
<td>2000</td>
<td>60</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>Gillig (2026-2074) (H2401-3) (2301-24)</td>
<td>2000</td>
<td>35</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Zeps (0001-21)</td>
<td>2000</td>
<td>40</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Gillig (1001-11) (H1012-22) (H1301-4)</td>
<td>2010</td>
<td>40</td>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td>New Flyer (0130-40)</td>
<td>2001</td>
<td>40</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Gillig (1401-12) (1501-13)</td>
<td>2014</td>
<td>40</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Nova (9901-28)</td>
<td>1999</td>
<td>40</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Gillig (2701-10)</td>
<td>2007</td>
<td>40</td>
<td></td>
<td>1.5</td>
</tr>
</tbody>
</table>

Flexible Service Vans - Doors open out, which makes use at level platforms impossible.
*Hybrids built the same as diesel equivalents
* (####) are series numbers above front door

Lug nut and fender flare issues are important to precision docking as they are a physical barrier to horizontal gap mitigation. When purchasing new BRT buses, this may only be a bus design specification that will need to be outlined, although this will vary depending on the flexibility of the manufacturer. However, when retrofitting old buses or considering the possibility of system interoperability, it is necessary to consider the variances that exist between different makes and models of buses. Table 4 above uses the bus fleet of the Indianapolis Public Transportation Corporation (IndyGo) in April 2016 as an example. The table has been color coded using the following criteria: less than 2” is green, equal to or above 2” but less than 3” is yellow, and greater than or equal to 3” is red. These colors are meant to reflect the likelihood of whether those buses would even be able to dock within an ADA compliant distance of 3” at a level-boarding platform. As you may note, age of a vehicle has no relation to the protrusion of its lug nuts or fender flares.

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26 See “Appendix 3 – System Interoperability Concerns” for more information.
Notice also that it is not always the lug nuts that protrude out the farthest, as fender flares can also create an issue. By no means should this be viewed as a less serious problem since fender flares won’t damage the station. Fenders can be costly to replace and perpetually damaged fenders or fender flares could serve to make the fleet look poorly maintained. This would reflect negatively on the company and potentially have a negative impact on ridership.
Appendix 3 – System Interoperability Concerns

Some agencies may seek to construct an open BRT system\(^{27}\) that allows for interoperability.\(^{28}\) In such cases, the determination needs to be made as to whether the goal is to have BRT buses operating off the BRT line, to have non-BRT buses operating on the BRT line, or both. For both of the electronic systems, there is nothing stopping a BRT bus from sufficient performance off a BRT line. However, to have non-BRT buses perform on the BRT lines the non-BRT buses will need to be equip with the technology, which is likely to create a significant financial barrier.

For the mechanical guidance systems, neither the Kassel Kerb nor the guide strip prevent interoperability in either direction as those two technologies are applied to the station and not to the buses. The only issue that would arise may come from variances in lug nut or fender flare protrusion.\(^{29}\) The guide wheel presents a significant challenge in both directions. If a guide wheel equip BRT bus attempts to dock at a bus stop that has a curb lower than the height of the guide wheel, the bus’s ability to kneel can be hindered. This is due to the possibility of the guide wheel striking the curb during the kneeling of the bus and breaking off. According to GCRTA, operators are trained to be wary if the kneeling of a bus is ever required at a stop location that is not a level-boarding platform. (Dr. Floun’say Caver, personal communication, February 29, 2016) Likewise, for a non-BRT bus to perform on a BRT line, it would be required to have a guide wheel installed. Although this likely wouldn’t be cost restrictive, the same level of caution mentioned earlier would need to be taken when the bus kneels along the non-BRT section of its route.

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\(^{27}\) An open BRT system is one which allows for bus lines to use the guideway of the BRT system while still being able to branch off of the BRT system’s guideway. (Walker, November 2016)

\(^{28}\) Interoperability occurs when BRT buses are able to fully operate off of a BRT line or when non-BRT buses are able to fully operate on a BRT line.

\(^{29}\) See “Appendix 2 – Lug Nut/Fender Flare Variance.”
References


Acknowledgements

Over the course of my research, I was able to interact and reach out to several individuals about the docking procedures used at their agencies. It’s hard to express the gratitude and respect I have for an industry of professionals that simply want to help everyone that has a question. The beautiful part about it all was how these individuals made it glaring obvious how much more I had to learn and how their sometimes simple comments sent me down the rabbit hole of deeper investigation. Their contributions, from translation to article suggestions to passing comments to swift kicks in the rear, unknowingly pointed out the flaws in my logic and have not only made this a better report but me a better human being and professional (I hope). Thank You Everyone, even if you don’t know it.

Alan Castree, Fleet and Depot Manager at the Department of Planning, Transport, and Infrastructure in Adelaide, Australia
Andrew Swanepoel, of MyCiTi in Capetown, South Africa
Brent Mould, Designer, CDM Smith, Indianapolis, IN, USA
Brian Pessaro AICP, Senior Research Associate, Center for Urban Transportation Research
Charles Carlson, Senior Manager, BRT/Small Starts Projects, Metro Transit, Minneapolis, MN, USA
Conrad Venema, Strategic Planning Manager, The Rapid in Grand Rapids, MI, USA
Darcy Rose, Doctoral Candidate, PhD in Linguistics at the University of Canterbury, Christchurch, New Zealand
Erik Van Hal, Urban Traffic and Transport Planner in Eindhoven, The Netherlands
Ernie Turner, Maintenance Manager, Lane District Transit in Eugene, OR, USA
Floun’say Caver PhD, Hayden District Director, Greater Cleveland Regional Transit Authority in Cleveland, OH, USA
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Nathan Goldberg, Manager of Transit Planning at RTC in Las Vegas, NV, USA
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