Digital Twin Approach to Accessibility Assessment of Public Transport

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Abstract

Accessibility assessment of public transport systems is essential for ensuring that infrastructure remains inclusive for individuals with disabilities or mobility impairments. However, the sheer size of public transport networks poses a significant challenge for the physical observation and assessment of accessibility. This paper presents an efficient approach to the accessibility assessment of tram transport based on simulation within a digital twin environment. We propose a novel framework that integrates advanced data acquisition and processing steps, including mobile mapping of the tram routes, determination of the deployment zone of the mobility aid lift (MAL), and the assessment of tram accessibility by simulating the MAL deployment in the digital twin. We present a case study of three tram routes in Melbourne, Australia, which demonstrates that the digital twin provides a practical and reliable tool for assessing tram accessibility. Our results also highlight the potential of the proposed digital twin approach for assessing the accessibility of other modes of public transport, such as train networks and bus stations.

1. Introduction

Accessible public transport is a cornerstone of modern society as it ensures equal access to mobility, employment, and education for people with disabilities. In Australia, the Victorian Government is committed to this goal through its Accessible Public Transport Action Plan 2020-24, which aims to improve public transport accessibility across all modes and meet the requirements of the Disability Standards for Accessible Public Transport (The VIC Government, 2020). A key priority of the Action Plan is upgrading tram stops to allow wheelchair access to existing high-floor trams equipped with the Mobility Aid Lift (MAL).

The MAL is a specialised boarding device consisting of a platform and lift mechanism stowed horizontally in a dedicated compartment beneath the tram floor, typically at the first set of double doors. When deployed, the platform slides out horizontally from its underfloor housing and lowers to the ground. Once the passenger is on the platform, it is raised to the level of the tram's internal floor. After boarding is complete, the platform is lowered slightly and retracted back into its underfloor compartment.

To deploy the MAL safely, the tram stop must meet certain accessibility requirements, including the availability of an accessible ramp, the absence of obstructions within the deployment zone, and a road camber and gradient that do not exceed predefined thresholds. Ensuring that these requirements are met, or identifying the required upgrades, necessitates a detailed assessment of all tram stops. However, the sheer size of the tram network poses a significant challenge for the detailed assessment of tram stops. Specifically, Melbourne has the largest tram network in the world, encompassing about 250 km of rail tracks and 1,600 stops (Yarra Trams, 2026). The extensive length and the large number of stops make the physical inspection and assessment of every stop highly impractical.

The emerging concept of digital twins offers a potential solution for the efficient accessibility assessment of tram stops. A digital twin is commonly defined as a virtual representation of a physical object or infrastructure, which allows real-time simulation as opposed to static geometric models (Fuller et al., 2020). By using a highly detailed and accurate digital replica of the tram network, accessibility criteria can be verified within the virtual environment by simulating the MAL deployment, eliminating the need for extensive real-world inspection. However, the efficient generation of a detailed and accurate digital twin that allows reliable simulation and verification of accessibility remains a significant challenge. In the context of urban digital twins, current research predominantly focuses on digital twins of buildings, which have different requirements and pose distinct challenges compared to vast, linear tram networks. A review of related literature reveals a knowledge gap in the development of digital twins specifically designed to support the accessibility assessment of tram transport (Jones et al., 2020; Mylonas et al., 2021; Irfan et al., 2024; Werbińska-Wojciechowska et al., 2024).

This paper presents an efficient approach to the accessibility assessment of tram stops based on simulation within a digital twin environment. We propose a novel framework that integrates several advanced data acquisition and processing steps: mobile mapping of the tram routes, determination of MAL deployment zone, and the final assessment of tram accessibility by simulating the MAL deployment in the digital twin. We present a case study focusing on three tram routes in Melbourne, Australia, which demonstrates that the digital twin provides a practical and reliable tool for assessing tram accessibility. Our results also highlight the potential of the proposed digital twin approach for assessing the accessibility of other modes of public transport, such as train networks and bus stations.

2. Proposed Approach

The proposed approach for creating a digital twin of the tram network and assessing stop accessibility consists of four main phases:

- Mobile mapping of tram routes
- Determination of MAL deployment zone
- Simulation of MAL deployment
- Accessibility classification of tram stops

The following sections provided a detailed description of the above phases.

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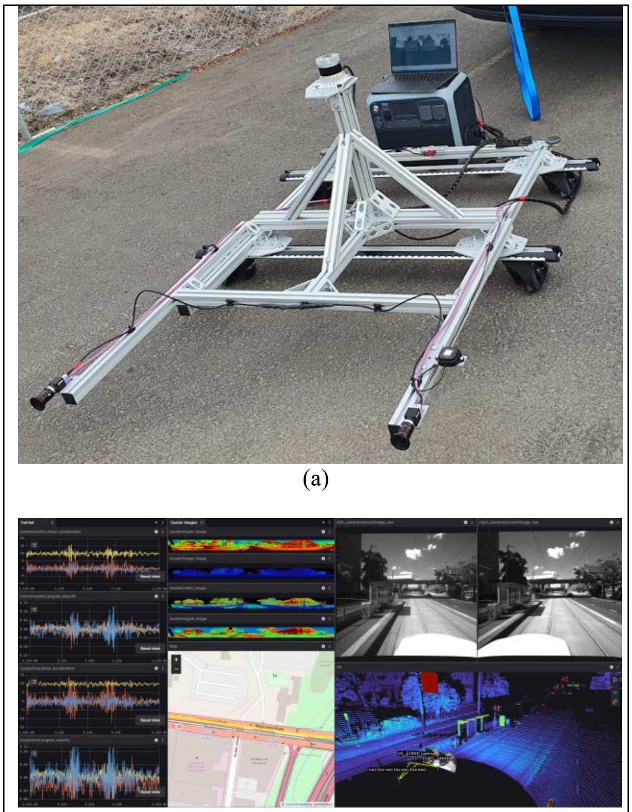
2.1 Mobile Mapping of Tram Routes

A prerequisite for digital twin development is accurate 3D spatial data, including lidar point clouds and imagery representing the geometry of tram routes and stops. While stationary data acquisition, such as terrestrial laser scanning, offers superior precision, it is impractical for this application given the extensive length of tram tracks and the large number of stops. Conversely, mobile mapping provides an efficient alternative for capturing 3D spatial data across the entire tram network, despite its comparatively lower precision.

We developed a customized mobile mapping system consisting of a GNSS receiver (UBLOX F9P), IMU (VectorNav VN-300), laser scanner (Ouster OS1-128), and two cameras (Blackfly S). Figure 1(a) shows the configuration of the sensors and the custom-built mount designed to carry the sensors onboard a vehicle driving on tram tracks. The sensors were calibrated, and data streams were time-synchronised and recorded using the Robot Operating System (ROS). Figure 1(b) shows an example of the data stream including stereo images, lidar scan, as well as position and attitude parameters measured by the GNSS/IMU.



(a)

(b)

Figure 1. The mobile mapping system custom-built for data collection on tram tracks (a), and the data streams time-synchronised and recorded using ROS (b).

2.2 Determination of MAL Deployment Zone

An accessible tram stop should provide adequate space for the MAL to be deployed safely. To assess this, the potential MAL deployment zone must be determined and analysed in the digital twin environment. Every tram stop features a vertical sign known as a flag, which marks the exact stopping point for tram drivers. The MAL deployment zone is defined as a rectangular area positioned relative to the flag. As shown in Figure 2, the MAL deployment zone measures 10 m in length, 2.8 m in width, and is located adjacent to the tram tracks, 7 m from the stop flag.

To simulate the MAL deployment and access the accessibility of the stop, the MAL deployment zone must be demarcated in the imagery and lidar point clouds. Since the size of the images and lidar scans of an entire tram route is prohibitively large, for each stop a subset of the data captured in a predefined radius of the stop was selected based on the horizontal coordinates of the stop available from the Victorian Open Data Portal (DataVic, 2026) and the georeferencing data collected by the GNSS/IMU during the mobile mapping. The reduced data size for each tram stop significantly streamlines the subsequent process of accessibility assessment.

The selected lidar scans were co-registered using the ICP algorithm (Besl and McKay, 1992) implemented in CloudCompare, and projected onto the images using the relative lidar-camera orientation parameters obtained through the calibration process. This facilitated the identification and 3D measurement of stop flags and rail tracks in the images. As illustrated in Figure 3, this projection enables making 3D measurements in image space.

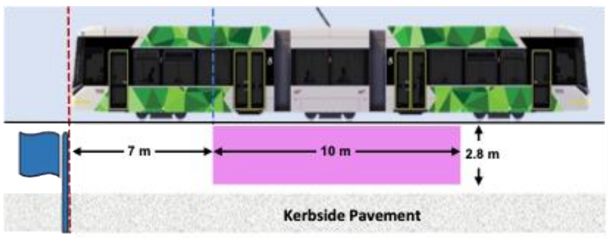


Figure 2. The MAL deployment zone defined as a rectangular area positioned relative to the flag and rail tracks.

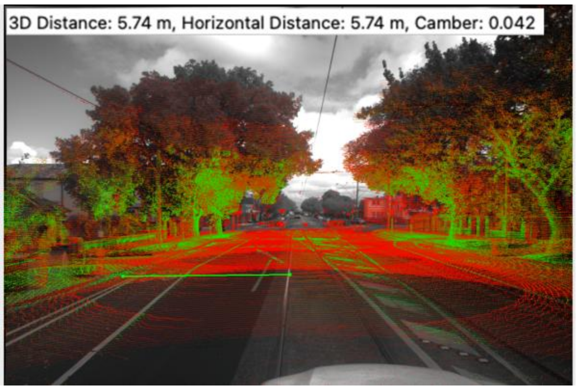
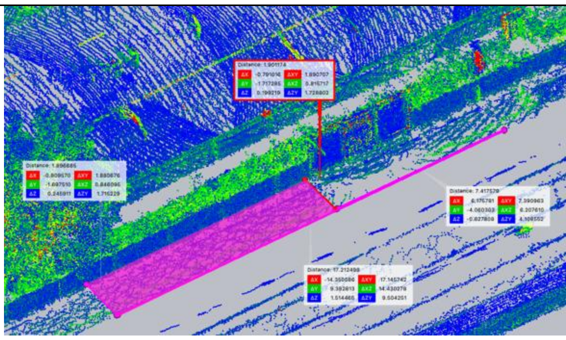


Figure 3. Lidar scans projected onto the image using the relative lidar-camera orientation parameters obtained through calibration.

Once the stop flag and rail tracks were identified and localised in the co-registered point cloud, the MAL deployment zone was demarcated based on its prespecified size and position relative to the flag and rail tracks. Figure 4 shows the MAL deployment zone visualised in a sample image and point cloud.

2.3 Simulation of MAL Deployment

The placement of the MAL deployment zone relative to the flag and rail tracks in the point cloud enables the simulation of MAL deployment at each stop. The simulation process involves placing a 3D CAD model of the tram on the rail tracks at the pre-specified distance to the flag, visualising the MAL deployment zone in the co-registered point cloud, and inspecting the operation of the MAL within the deployment zone. The simulation was performed interactively in CloudCompare by visualizing the point cloud, the MAL deployment zone, and CAD models of the tram and the MAL in three different configurations: (i) stowed, (ii) extended and raised to the tram floor level, and (iii) extended and lowered to ground level. Each configuration was loaded in a separate layer so that by toggling layer visibility the MAL's operation and clearance could be inspected. The simulation provided a visual means to ensure there is adequate space for the MAL to be deployed, lowered, raised, and stowed, allowing passengers with wheelchairs or mobility aids to safely mount or disembark the tram. Figure 5 illustrates the process of simulating the MAL deployment in the virtual environment.



(a)

(b)

Figure 4. The MAL deployment zone demarcated in the point cloud (a) and the image (b).

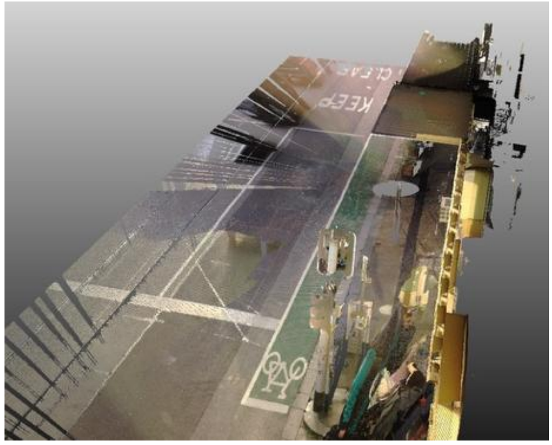
2.4 Classification of Tram Stops

The accessibility of each tram stop was assessed according to the following criteria:

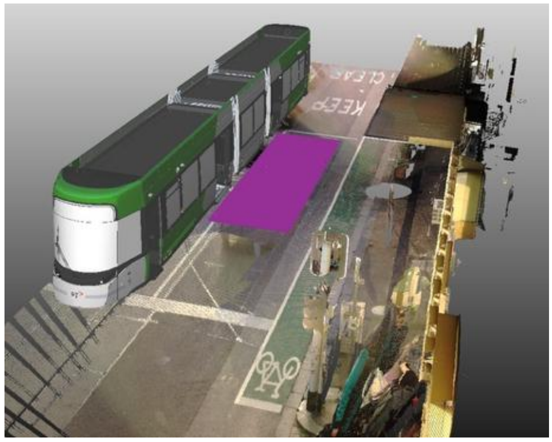
- Presence of an accessible ramp
- Absence of obstructions within the deployment zone
- Road camber and gradient within the deployment zone not exceeding a predefined threshold

The first two assessment criteria can be visually verified through the simulation of MAL deployment. Road camber and gradient are the lateral and longitudinal slope of the road surface within the deployment zone. These need to be accurately measured and compared against predefined thresholds. As shown in Figure 4, these measurements can be made in the image space as well as the point cloud.

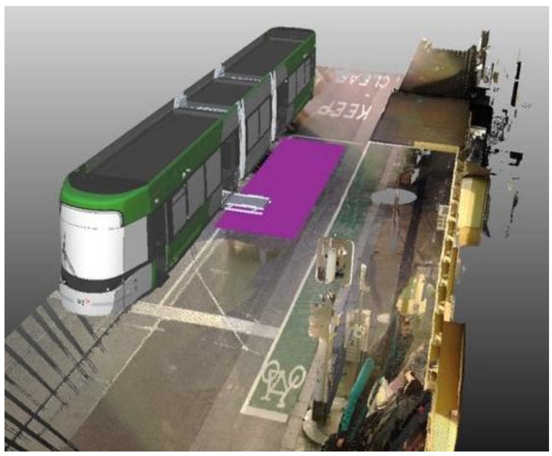
Figure 6 shows an example visualisation of the MAL deployment simulation used for assessing the accessibility criteria. Based on this assessment, each stop was classified into one of five classes as described in Table 1.



(a)



(b)



(c)

Figure 5. Simulation of MAL deployment. The 3D position of the rail tracks and the stop flag in the point cloud (a) guides the correct placement of the tram and the deployment zone (b) within which the MAL is deployed (c).

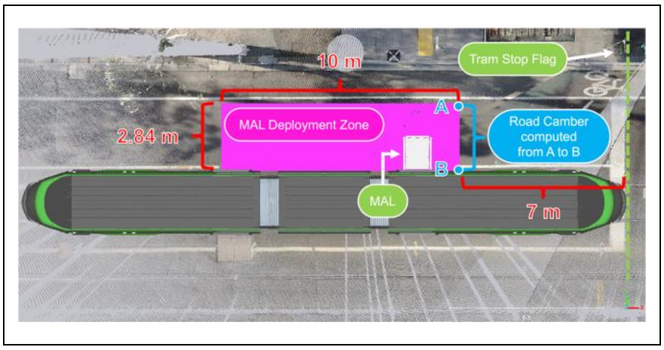


Figure 6. Top view of simulated MAL deployment used for assessing the accessibility criteria.

Classification	Description
Compatible	Stop is already compatible with MAL deployment.
Feasible	Stop needs infrastructure upgrades to be compatible with MAL deployment.
Not possible	MAL deployment is not possible (Right hand opening).
Platform upgrade required	Platform stop needs infrastructure upgrades to be accessible.
Assessment not required	Platform stop is accessible.

Table 1. Accessibility classification. The first three classes are applicable to tram stops without a dedicated level-access platform, while the last two apply to platform stops only.

Some stops feature level-access platforms at the height of the tram floor, enabling passengers using wheelchairs or mobility aids to board and disembark the tram without requiring the MAL. For these stops, the accessibility assessment focuses on whether infrastructure upgrades, such as ramp construction, are required. Conversely, a small number of stops are situated on the right-hand side of the tram, where MAL deployment is prohibited. For all other stops, the assessment determines if the current geometry is compatible with the MAL deployment or if specific upgrades are necessary to make MAL deployment feasible.

3. Case Study

To demonstrate the practical application of the proposed accessibility assessment framework, a case study was conducted across three tram routes in Melbourne, Australia. The custom-built mobile mapping system, shown in Figure 1, was mounted atop a Toyota HiLux utility vehicle operated by Yarra Trams. Data collection was conducted by driving the vehicle along the three tram routes in both directions. Stereo imagery, lidar scans, and GNSS/IMU positioning and attitude measurements were time-stamped using the CPU clock within ROS and stored for subsequent processing.

Overall, the mobile mapping campaign covered 64.4 km of tram tracks, yielding approximately 460,000 stereo images and 154,000 LiDAR scans. A small number of stops, which were insufficiently captured in the mobile mapping data due to occlusions, were subsequently surveyed using a terrestrial laser scanner to supplement the dataset.

For each tram stop a subset of the imagery and lidar scans was selected based on the known coordinates of the stop obtained from the Victorian Open Data Portal. These data were co-registered, and the MAL deployment zone was determined following the method described in Section 2.2. Through the simulation of MAL deployment and the measurement of road camber and gradient, each tram stop was classified into one of the five accessibility classes listed in Table 1.

Table 2 summarises the results of accessibility assessment for the tram stops along the three routes. As it can be seen, out of the total 206 tram stops in both directions 54 were determined accessible (platform) or compatible with MAL deployment, while 150 were classified as requiring upgrades. Two of the stops in Route 59 were classified as “not possible”, because they were located on the right side of the tram making the MAL deployment not possible. Figure 7 depicts the accessibility assessment results for the tram stops along Route 59.

The point clouds and 3D CAD models used for the MAL deployment simulation and tram stop accessibility assessment were integrated with the Digital Twin Victoria (DTV) platform. DTV provides access to an extensive catalogue of open data from various Australian government sources, complemented by a visualisation service capable of displaying 2D, 3D, time-dynamic, and real-time data through a web browser (DTV Platform, 2026). To facilitate the integration with the DTV, the point cloud data were converted to the Cloud Optimized Point Cloud (COPC) format, enabling efficient web-based visualisation via the Cesium engine. Figure 8 shows the MAL deployment simulation visualised on the DTV platform.

Classification	Route 57	Route 59	Route 82
Compatible	6	2	2
Feasible	59	49	25
Not possible	0	2	0
Platform upgrade required	4	11	2
Assessment not required	2	29	13
Total	71	93	42

Table 2. Accessibility assessment results for tram stops along three routes in Melbourne, Australia.

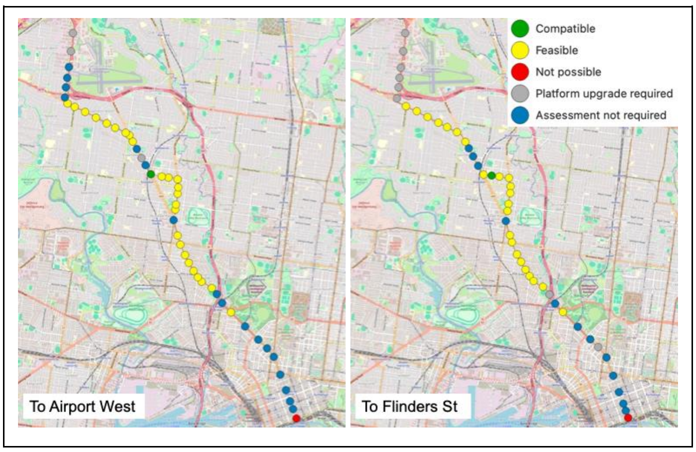


Figure 7. Accessibility assessment results for tram stops along Route 59, overlaid on a base map.

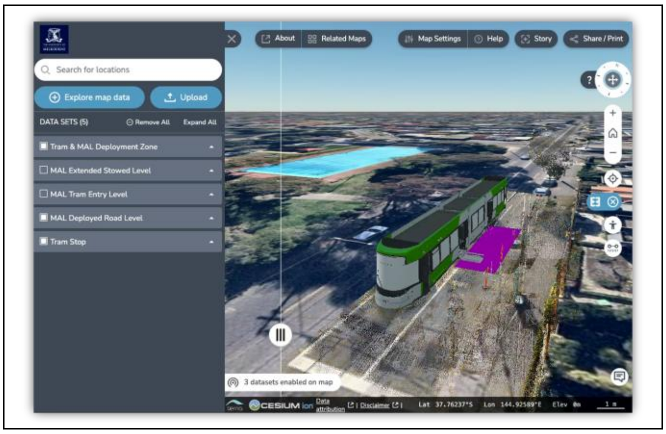


Figure 8. MAL deployment simulation on the DTV platform.

4. Discussion

In this study, the identification of stop flags and rail tracks in the co-registered imagery and point cloud data as well as the accessibility classification of the stops were done interactively due to the stringent accuracy requirements, which took precedence over the efficiency. These processes can be automated to further reduce the time, cost, and labour-intensiveness of accessibility assessment in the digital twin environment.

Stop flags and rail tracks can be automatically detected in the co-registered imagery and point cloud data using existing machine learning object classification and segmentation models (He et al., 2020; Luo et al., 2020). To minimise the burden of manual data annotation, large pre-trained models, such as YOLO (Wang et al., 2024), SAM (Kirillov et al., 2023), DINO (Oquab et al., 2023; Siméoni et al., 2025), Point Transformer (Wu et al., 2024), and various vision-language models (Li et al., 2025) can be leveraged. These models are generally pre-trained on datasets comprising common objects, e.g., MS COCO (Lin et al., 2014), but they can be fine-tuned using a small annotated dataset to detect and segment other objects of interest (Ying et al., 2025).

The accessibility classification process can be automated by identifying the ground surface within the MAL deployment zone, e.g., using plane fitting (Khoshelham, 2016; Zhao et al., 2022), and detecting the accessibility ramp and potential obstacles above the ground plane. Road camber and gradient can also be measured automatically by analysing the ground points along the principal axes of the MAL deployment zone.

5. Conclusions

We presented an approach to accessibility assessment of tram stops based on simulation within a digital twin environment. The digital twin was generated from georeferenced and co-registered imagery and lidar point clouds captured by a custom-built mobile mapping system along the tram routes. The accessibility of each tram stop was assessed by simulating the MAL deployment within a deployment zone demarcated in the co-registered point cloud data. A case study on three tram routes in Melbourne, Australia, demonstrated that the digital twin provides a practical and reliable tool for assessing tram accessibility. Despite the manual interactions required during the assessment, the proposed digital twin approach is significantly more efficient than physical inspection of tram stops in terms of time, cost and labour. The results also highlight the potential of the proposed digital twin approach for assessing the accessibility of other modes of public transport, such as train networks and bus stations.

Future work will focus on the development of methods for automating the simulation of MAL deployment and accessibility classification of tram stops. This will include automated detection of stop flags, rail tracks, accessibility ramps, and potential obstacles within the MAL deployment zone in the digital twin environment. Future research will also explore the extension of the digital-twin-based accessibility assessment approach to other modes of public transport.

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