- 1 **RFID** and Wireless IoT Technologies for Transportation Maintenance Operations and
- 2 Asset Management
- 3

### 4 Jay Hwasung Jung

- 5 Department of Computer Science
- 6 University of Vermont, Burlington, VT 05405
- 7 Email: jjung2@uvm.edu
- 8

# 9 Wenzhe Chen

- 10 Department of Electrical & Biomedical Engineering
- 11 University of Vermont, Burlington, VT 05405
- 12 Email: <u>wchen4@uvm.edu</u>
- 13

## 14 Byung Suk Lee

- 15 Department of Computer Science
- 16 University of Vermont, Burlington, VT 05405
- 17 Email: <u>bslee@uvm.edu</u>

# 1819 **Tian Xia**

- 20 Department of Electrical & Biomedical Engineering
- 21 University of Vermont, Burlington, VT 05405
- 22 Email: txia@uvm.edu
- 23
- 24 Word Count: 4,429 words + 0 tables = 4,429 words
- 25
- 26
- 27 Submitted [08/01/2023]
- 28
- 29
- 30

### 1 ABSTRACT

2

3 This paper introduces an innovative transportation asset management approach that harnesses the 4 capabilities of radio-frequency identification (RFID) technology. By utilizing RFID's remote 5 sensing capabilities, real-time detection of transportation assets is achieved, leading to significant 6 improvements in operational efficiency. There exist alternative technologies such as barcode, GPS, 7 and NFC that are used in asset management. However, unlike barcodes, RFID can store data 8 directly on the tag, enhancing information capacity. Moreover, RFID's indoor applicability 9 distinguishes it from GPS; and its broader range sensing surpasses the limitations of NFC, making 10 it a comprehensive and effective tool for asset management across various settings. The study investigates the system configuration, RFID devices, software program and database. In our 11 12 experiments, vehicles, particularly trucks, are used as the objects to showcase the practicality and 13 viability of the system configuration for asset management using RFID technology. To facilitate 14 experiments, open-source Graphic User Interfaces (GUIs) programs are customized to meet the 15 requirements of the proposed solution. Additionally, a sample Web GUI is developed to 16 demonstrate the feasibility and practicality of integrating various RFID readers. Field tests are conducted to evaluate the system performance and reveal factors that should be carefully 17 18 considered for actual deployment. 19

20

21 Keywords: Radio-frequency Identification (RFID), Transportation Assets Management System,

22 Stationary RFID Reader, Handheld RFID Reader, Database, REST API

#### 1 **INTRODUCTION**

2

3 As highlighted in the Executive Brief by the US DOT FHWA [1], effective transportation asset

4 management is crucial for maximizing long-term sustainability, accountability, and performance 5

while addressing public concerns about the health and safety of transportation assets. To achieve

6 these goals, transportation agencies require a reliable framework that allows them to strategically 7 manage diverse assets, including construction tools, equipment, and infrastructure, in an automatic,

8 uniform, and efficient manner [2-3]. Data-driven decision-making is essential to balance various

9 trade-offs between business needs and service operations.

10

11 A significant aspect of asset management involves accurately tracking and recording attributes

12 for each individual asset item. While using barcodes to assign unique IDs to assets is a simple

13 approach, it comes with critical drawbacks. Barcode scanning requires a direct line of sight and

14 can be affected if the barcode is contaminated or covered. Additionally, close proximity to the

15 barcode is necessary for scanning, making it labor-intensive and error-prone, especially when

16 dealing with a large asset inventory. The limitations of barcode stickers in automatic and

17 efficient transportation maintenance operations and asset management are exacerbated by the

absence of data storage capabilities, which restricts their utility in providing comprehensive data 18

19 about assets or maintenance needs. RFID, in contrast, allows for the storage of extensive

20 information on a tag, enabling quick and accurate access to data crucial for transportation

21 maintenance and asset management. The absence of data storage in barcode stickers hampers

22 their ability to offer the detailed, real-time insights needed for optimal operational efficiency and

management. 23

24 With advancements in wireless communication, computing, and semiconductor technologies, the

25 Internet of Things (IoT) has emerged as a powerful method to design intelligent transportation

26 systems [4-8]. In this project, we propose exploring radio-frequency identification (RFID) and

27 other wireless IoT technologies to develop an automated solution for efficient transportation

- 28 maintenance operations and asset management.
- 29

30 RFID, a wireless tracking technology, enables remote activation, reading, and writing of data between an RFID reader and an RFID tag attached to or embedded in an object. The technology 31 32 consists of three main functional elements: an RFID reader, an RFID tag, and firmware. RFID 33 readers send encoded electromagnetic signals to interrogate RFID tags, which respond by 34 transmitting their ID information or other stored data. Compared to barcodes, RFID offers 35 robustness, automation, and no line-of-sight requirement, making it suitable for various 36 applications such as asset tracking, supply chain management, security, and access control.

37

38 While alternative technologies such as the Global Positioning System (GPS) and Near Field 39 Communication (NFC) are available, RFID stands out for its ability to operate effectively in indoor 40 environments. Unlike GPS, RFID is capable of functioning indoors, making it highly versatile. 41 Additionally, when compared to NFC, RFID offers longer-range sensing capabilities.

42 43

44 In terms of software, while standard business software is increasingly integrating asset 45 management support, there remains a critical gap in fulfilling essential criteria. Particularly, for

effective asset management utilizing RFID technology, systems should excel in managing assets 46

individually, facilitating precise location tracking, providing real-time updates on an asset's physical status or quality, allowing the definition of triggers based on specific asset conditions, and maintaining a comprehensive information history for each asset. RFID-enabled asset management systems hold the potential to address these criteria, offering a level of granularity, accuracy, and historical insight that enhances overall operational efficiency and decision-making processes within an organization.[13]

7

8 The advantages of RFID technology make it a key enabler for developing automated transportation 9 maintenance operations and asset management systems. A previous study proposes RFID 10 technology for traffic signage inventory management in transportation assets [9-11]. RFID tags are attached to signs, and a mounted reader on a survey vehicle performs tag interrogation while 11 12 driving. A handheld reader scans at close range, while a remote database manages data, allowing 13 real-time communication. The system is adaptable to rural and urban environments, with an 14 adaptive mechanical structure for obstacle-prone areas. It includes a local database for addressing 15 connectivity issues and easy cloud access.

16

17 In this project, we broaden the scope of RFID technology to enhance general transportation asset 18 maintenance and management. By utilizing vehicles as sample objects, we showcase the 19 technology's efficiency and accuracy in transportation asset monitoring and maintenance. 20 Different types of RFID readers, including stationary readers and handheld readers, are utilized to perform remote or short-distance scans under diverse environmental settings and application 21 22 scenarios. This system can accurately track the locations of assets and monitor their presence or 23 movement within or from the garage or facility. It enables real-time access and editing of asset 24 attribute data, which can significantly improve the efficiency of transportation projects' planning, 25 design, fabrication, construction, operation, maintenance, and decision-making processes.

- 26
- 27 **METHODS**

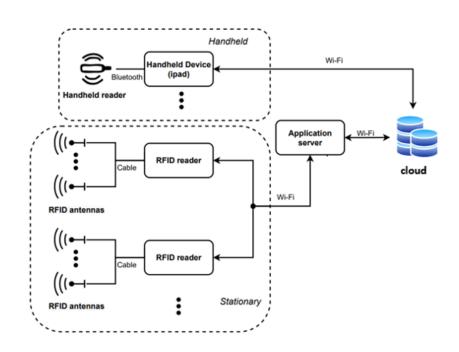


Figure 1. The system diagram of RFID-based asset management system

#### 1 • System configuration

2 As Figure 1 shows, the system consists of RFID readers, RFID tags, an application server with a 3 graphical user interface (GUI), and the asset database. To achieve application flexibility, two types 4 of RFID readers will be used which include portable handheld readers and high-performance 5 stationary readers. The handheld reader connects to a mobile IOS device (e.g., an iPad or an 6 iPhone), which processes the data, displays the retrieved information from the VTrans database, 7 and accesses the database for editing. The stationary RFID readers will be mounted at the desired 8 positions and equipped with multiple antennas to expand scan direction and coverage. The 9 application server remotely controls all readers and processes the received data, and it also accesses 10 a local database that is synchronized with the VTrans database.

11

12 In practical use, stationary readers and handheld readers can scan RFID tags and retrieve asset

- 13 information in real-time. When a tag is detected, its tag ID will be displayed on a reader screen.
- 14 Then, the reader operator can retrieve information from the database and make modifications if
- 15 necessary. In addition, the reader will measure the received signal strength (RSSI) which indicates 16 the reading performance, allowing the operator to fine-tune system operation when needed.
- 16 the reading performance, allowing the operator to fine-tune system operation when needed.
  17



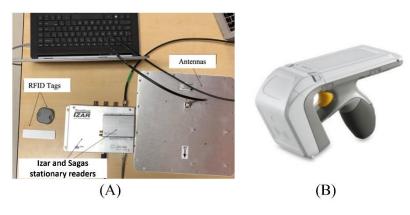


Figure 2. RFID devices: (A) stationary readers, antenna, RFID tags. (B) handheld RFID

18 • RFID tags

19 In our system, passive RFID tags are selected to use.. Passive RFID tags are powered by the 20 electromagnetic energy emitted by an RFID reader, eliminating the need for an internal battery. 21 This characteristic makes passive tags a cost-effective choice for large-scale deployment due to 22 their lower manufacturing cost. Additionally, the absence of a battery means that passive tags 23 require minimal maintenance, making them easier to deploy and manage over time. On the other 24 hand, active and semi-active RFID tags are equipped with a battery, allowing them to continuously 25 broadcast signals over longer distances compared to passive tags. However, this comes with the 26 drawback of higher cost and the need for battery recharging or replacement. As a result, active and 27 semi-active tags are more suitable for monitoring or tracking applications where battery 28 maintenance is feasible. For our inventory management system, which requires mass deployment 29 of RFID tags and cost-effective maintenance, passive tags are the preferred choice.

30

31 In our system, we have specifically selected the Omni-ID Flex 1200 and Omni-ID Exo 750 (Figure

- 32 2A) as the passive RFID tags. Both types of tags operate within the same frequency band of 865-
- 33 956 MHz. The Omni-ID Exo 750 is encased in a hard-plastic package, providing added durability

compared to the Omni-ID Flex 1200. This selection allows us to ensure the reliability and longevity
 of the RFID tags in our transportation asset management system.

3 4

### • Stationary Readers

5 Two stationary RFID readers tested are Sargas and Izar readers (**Figure 2A**). The antennas used 6 are SecureControl Invengo antenna and MTI antenna. Both readers are compliant with EPC Gen2 7 standard, and their operating frequencies are within FCC authorized 902-928 MHz range. Both are 8 integrated with a Debian Linux OS making the remote control possible. The difference is that Izar 9 has 4 antenna ports with RF-BNC type connection, while Sargas only has 2 antenna ports with 10 RF-SMA type connection, which means the former can support 4-channel scan while the latter 11 supports 2-channel scan.

12

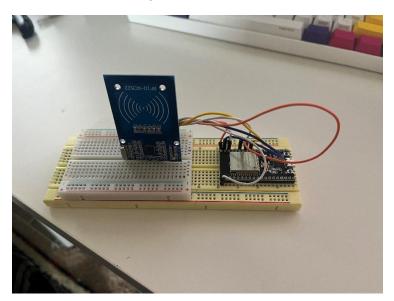
### 13 • Handheld Readers

The handheld reader is integrated into the system allowing for on-site individual tag interrogation to display or modify the relevant tag information (**Figure 2B**). A mobile RFID reader software program has been developed to operate the handheld reader. The program is customized to support filtering, reading, displaying, and saving RFID tag data in the same manner as the stationary reader GUI program. Database connection and data synchronization are also developed.

19

In deployment, the handheld reader connects to an iOS device via Bluetooth. Upon activation, the reader performs a close-range scan of the RFID tag, checks the tag ID, retrieves the pertinent tag data and attributes of the asset item from the database. This information is then displayed on the screen of the iOS device. The reader allows for the editing of tag data, which can be written back to the database server. Any modifications made to asset attributes are instantly updated both locally on the reader and remotely in the database on the server. This seamless interaction ensures realtime synchronization of asset information between the handheld reader and the central database.

- 27
- 28 Low Cost MFRC 522 RFID Reader for Arduino/ESP 32



29 30

Figure 3. MFRC 522 RFID Reader for Arduino/ESP 32

1 2

3 In light of concerns about the cost of RFID readers in the assets management system, we address 4 this challenge by conducting a test using the MFRC 522 RFID Reader for Arduino or ESP 32, 5 shown in Figure 3. Although the MFRC 522 RFID Reader has inferior specifications compared to 6 stationary and handheld readers and operates at a different radio frequency, the test successfully 7 showcases the potential for developing RFID readers independently, without being limited by 8 existing market constraints. Despite its lower cost, the MFRC 522 RFID Reader demonstrated 9 seamless connectivity with the database.

10

11 This test highlights the possibility of reducing the overall cost of the RFID asset management 12 system by exploring alternative RFID reader options without compromising its functionality and 13 performance. Thus, we can develop a hybrid system that integrates different RFID devices and 14 specifications holding the potential to strike a balance between cost and performance for managing 15 various types of asset items. By strategically integrating diverse RFID devices and specifications 16 into the asset management system, we can achieve a versatile and adaptable solution that meets 17 the unique demands of different assets while optimizing costs and ensuring effective performance. This flexibility can be a significant advantage in transportation asset management, where assets 18 19 may vary widely in size, location, and operational requirements. 20

22

21 • *Graphic User Interface (GUI)* 

Ð,	Tag Inspector   W	Inite EPC User Memory Lock Tag Untre	nable Authenticate	Detabase				2 Settings/Status	
	Reader	EPC	Time Stamp (ms)	RSSI (dBm)	Read Count	Antenna	Status	· Correct	
- 14	igai-7b7554	5441475400000000000000000000000000	044328.400 AM	-70	92	1	OUT	Connect	
	izar-76/7514	48515000000000000979025	0443/28460 AM	-75	52	1	NONE	Reader Name : IZAR-707134	
	izar-767534 izar-767534	38E3000018CFC7400000C58 56414F540000000000000000000000055	04.43/28.460 AM 04.43/28.460 AM	-61 -51	58 70	1	NONE		
	itar-767534 itar-767534	36414554000000000000000000000000000000000	044328460 AM	-51	10		NONE	Transport Loge	
1.1	itar-767534	188300000191ECC400001609	04(43)28,461 AM	-45	39	1	NONE	CONTRACTOR INCOME	Ruthesh Web GE Class
	icar-767534	564147540000000000000000000000000000000000	044328461 AM	-68	85	1	OUT.	Region : NA -	
	icar-767534 icar-767534	38E400000118DEA8400000605 00807A1494160A9018000038	GENERAL AM	-70	55		NONE	cload/Save Profile	
10	icar-7b7534	00807A1494418ACF00000112	04:43-28.461 AM	-79	13	Ť	NONE	Load Save	
	izer-767534	5541-47540000000000000000000000000077	04:43:28.461 AM	-59	68	2	NONE	1	
	izer-767534 izer-767534	20180703087264021A901C44 000000000000000000103245	0443/28461 AM 0443/28462 AM	-62 -68	45	2	OUT NONE	Read/Write Options	
	utar-767534	38E300000196A360000063D	044325462 AM	-75	14	1	NONE	Performance Turing	
	itar-767534	80342CD84430650000007A4	044338462 AM	-74	6	*	NOW	Ferformance Methics	
	itar-767534 itar-767534	00807A1494168010180006880	04-42-25-462 AM	-73 -77	1	1	NONE	Ouplay Options	
	icar-767534	56414/5400000000000000000000000	04:43:28:465 AM	-73	19		NONE	Status/Mersion Infly	
	a de tra ace	W-164			Your P	ecord is	: Here!		
	0								
				_					
lorne	e Plate:	T 10154		- 1			ID and Periods		
				-	Type Yo		ID and Periods		
icerse Make &	e Plate:	T 10154		-	Type Yo Starting date	e 07/27/2023	ID and Periods		
icerse lake & danufa	e Plote & Model actured (Mart)	T 16154 International		- 1	Type Yo Starting date	our truck	ID and Periods		
Donne Marke & Markulje Driver ©	e Pote & Model Ischured (Near) ©	T 16164 International 2000 Al		1	Type Yo Starting date	e 07/27/2023	ID and Periods		
icone data & danula biver C koputat	er Plote: 6 Model Jactured (New); 10 10 10 Date:	T 16964 International 2000 AJ 2002-12-20-0219/28			Type Yo Starting date	e 07/27/2023	ID and Periods		
icone data & danula biver C koputat	e Pote & Model Ischured (Near) ©	T 16164 International 2000 Al		1	Type Yo Starting date Ending date submit	our truck 07/27/2023 07/30/2023	ID and Periods	-07-30	
License Manufa Driver (C Acquist Deptoyr	er Pfeter 8. Model Jachurell (Hear) 40. Hillon Date: urteent Date:	T 16964 International 2000 AJ 2002-12-20-0219/28		1	Type Yo Starting date Ending date submit	our truck 07/27/2023 07/30/2023 s of 2023	ID and Periods 3-07-27 ~ 2023		
Dome Make & Manufa Driver & Nogulat Deptopr	er Plate: 8. Model Jachurell (Maar) ID: Hiton Date: yment Date:	T 19164 International 2000 Al 2002-10-20 02199.28 2002-10-40 02195.28			Type Yo Starting date Ending date submit	s of 2023	ID and Periods 3-07-27 ~ 2023	gpsAddress	status_JN_00_00T
Cicerne Make & Manufa Driver C Nogalait Top C Manufa	e Piete. 6 Model ectured (Next) 60 vition Date vition Date content Date	T 14154 Metroverset 3000 Ja 2022-0-2010 219326 2023-0-2010 219326 Before Sectore000000000000000000000000000000000000			Type Yo Starting date Ending date submit	s of 2023	ID and Periods 3-07-27 ~ 2023 Date 2023-07-29 14:01:27	gpsAddress ESP32	status_IN_OR_OUT
Cicerne Make & Manufa Driver C Nogalait Top C Manufa	e Piete. 6 Model ectured (Next) 60 vition Date vition Date content Date	T 19194. Hermuthwali 2009 Al 2022 -12-20 02 199.28 2022 -12-40 02 199.28 (SANT 54000000000000000000000000000000000000			Type Yo Starting date Ending date submit	s of 2023	ID and Periods 3-07-27 - 2023 Date 2023-07-29 14:0127 2023-07-29 15:47:43	gpsAddress ESP32 SARGAS-+4065/	}
Cicerne Make & Manufe Driver (C Acquist Deployer Trig (C) Manufic Deployer	e Piete. 6 Model ectured (Next) 60 vition Date vition Date content Date	T 14154 Metroverset 3000 Ja 2022-0-2010 219326 2023-0-2010 219326 Before Sectore000000000000000000000000000000000000			Type Yo Starting date Ending date submit	s of 2023 10-111 16-272 17-364	ID and Periods 3-07-27 ~ 2023 Date 2023-07-29 14:0127 2022-07-29 19:0743 2023-07-29 19:0743 2023-07-29 19:0743	gpsAddress ESP32 SARGAS-e40655 Icar-767534.local	ntatus, IN, OR, OUT ) ) 0
Come Make & Manufa Diver C Nogalat Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy	e Rete: & Model bekured (Mark) © uiten Date: urrent Date: Statue Date: statue: urrent urrent urrent	T 19194. Hermuthwali 2009 Al 2022 -1-2 80 219 238 2022 -1-9 40 219 303 (SANT 54000000000000000000000000000000000000			Type Yo Starting date Ending date submit	s of 2023 10-111 10-	D and Periods	gpsAddress 85932 SARGAS-e40059 Izer-7b7534.local izer-7b7534.local	0
Come Make & Manufa Diver C Nogalat Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy	e Rete: & Model bekured (Mark) © uiten Date: urrent Date: Statue Date: statue: urrent urrent urrent	T 1918.4 Hermithonal 2009 2012 2012-07-08 (21193.8) 2012-07-08 (21193.8) 2012-07-0			Type Yo Starting date Ending date submit	s of 2023 10-111 16-272 17-364 17-364 17-364 17-364	D and Periods	gpsAddress 5912 5APGA5-e3050 uar-75753Alocal uar-75753Alocal uar-75753Alocal	0
Come Make & Manufa Diver C Nogalat Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy Diploy	e Rete: & Model bekured (Mark) © uiten Date: urrent Date: Statue Date: statue: urrent urrent urrent	T 1918.4 Hermithonal 2009 2012 2012-07-08 (21193.8) 2012-07-08 (21193.8) 2012-07-0			Type Yo Starting date Ending date submit	our truck or/27/2023 or/30/2023 s of 2023 0 10-111 16-272 17-964 17-964 17-964	D and Periods 3-07-27 - 2023 Date 002-07-29 16:072 002-07-29 16:074 0021-07-27 07126 0021-07-27 07126 0021-07-27 07126	gpsAddress 59/32 5ARGA5-e40657 0ar-7b7554.kocal 0ar-7b7534.kocal 0ar-7b7554.kocal 0ar-7b7554.kocal	
Come Male & Manufa Driver C Nopilar Tay D Nopilar Tay D Nopilar Tay D	e Pate. 6. Model actured (Nex). 60. ether Date wreed Date wreed acture Date. wreed acture Date.	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bour truck           07/27/2023           07/30/2023           s of 2023           10-111           16-212           17-984           17-984           17-984           17-984           17-984           17-984           17-984           17-984           17-984	D and Periods 3-07-27 - 2023 Date 002-07-29 1407-29 002-07-29 1407-29 002-07-29 1457-29 002-07-27 0712-59 002-07-27 0712-59 002-07-29 1407-59 002-07-27 0712-59 002-07-27 0712-59 002-07-29 1407-59 002-07-29 1407-59 002-07-27 0712-59 002-07-27 072-59 002-07-27 072-59 002-07-27 002-07	pps.8.doitness ESP32 SARGA3-e40055 Iran-7b7534.bocal Iran-7b7534.bocal Iran-7b7534.bocal Iran-7b7534.bocal	) 0 1 0
Come Nate & Nanda Oliver C Nopilar Deployr Ing C Nopilar National	e Plate: 8. Model: 9. Model: 90. 90. 90. 90. 90. 90. 90. 90. 90. 90.	T 1918.4 Hermithonal 2009 2012 2012-07-08 (21193.8) 2012-07-08 (21193.8) 2012-07-0			Type Yo Starting date Ending date submit	Dur truck           07/27/2023           07/	D and Periods	905-8-087-95 5890-32 5890-32 687-7575-30 Alocal 687-7575-30 Alocal 687-7575-30 Alocal 687-7575-30 Alocal 687-7575-30 Alocal 687-7575-30 Alocal	
Come Nate & Nanda Oliver C Nopilar Deployr Ing C Nopilar National	e Pate. 6. Model actured (Nex). 60. ether Date wreed Date wreed acture Date. wreed acture Date.	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           ©7/27/2023           ©7/30/2023           ©7/30/2023           S of 2023           Ib           10-11           16-272           17-864           17-864           17-864           17-864           17-864           17-864           17-864	D and Periods	posAddress Esirigi SARGAS-a-dototi cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel cert-70/73A Accel	) 0 1 0
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bur truck           07/27/2023           07/30/2023           07/30/2023           s of 2023           10-111           15-272           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964           17-964	D and Periods	pstAddress ESP32 SARCAR-4-0055 Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel Gen7b753Abcel	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	bur truck           07/27/2023           07/	D and Periods	gos Address Esp32 san Anna – anoso ear - 77733 A Incel ear - 77733 A Incel	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/27/2023           0           07/27/2023 </td <td>D and Periods</td> <td>Services ESP32 GARGA-40029 Garch29304.40039 Garch29304.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch2934.0001</td> <td></td>	D and Periods	Services ESP32 GARGA-40029 Garch29304.40039 Garch29304.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch29334.0001 Garch2934.0001	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           07/27/2023           07/27/2023           07/27/2023           07/27/2023           07/30/2023           0           10-111           10-212           10-344           17-344	D and Periods	gosAddress Es932 santos 4-4000 ser 7275134 focal ser 7275134 focal ser 7275134 focal ser 7275134 focal ser 727534 focal	
kome data 6 danuta Monte Copulati Notori Copulati Copulati Notori Copulati Not	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           01/27/2023           07/30/2023           07/30/2023           0           0           10-111           16-272           17-364           18-36           19-36           19-36	D and Periods	seckdones ESP32 GRIGA-40087 GR	
kome data 6 danuta Monte Copulati Notori Copulati Copulati Notori Copulati Not	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           07/27/2023           67/30/2023           50 7/30/2023           50 7/30/2023           50 7/30/2023           10-11           10-22           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           7-964           9-96           29-96	D and Periods	gouldatese Espisiz santana - acosor uar -772/514 Ancal uar -772/514 Ancal	
kome data 6 danuta Monte Copulati Notori Copulati Copulati Notori Copulati Not	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bur truck           01/27/2023           07/30/2023           07/30/2023           0           0           10           10           10           10           11           0           17           17           17           17           17           17           17           17           17           17           17           19           19           19           19           19           19           19           19           19           19           19           19           19           10           10           10           10           10           10           10           10           10           10           10           10           10           10           10           10 <td>D and Periods</td> <td>Sec Address ESP32 GATGA-40027 Garch2934 Ascal Garch2934 Ascal</td> <td></td>	D and Periods	Sec Address ESP32 GATGA-40027 Garch2934 Ascal Garch2934 Ascal	
kome data 6 danuta Monte Copulati Notori Copulati Copulati Notori Copulati Not	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Our truck           07/27/2023           07/27/2023           07/27/2023           s of 2023           0           10-111           16-223           07-384           08-38           08-38           09-38           09-38	D and Periods	spukAddress ESP32 SARAA-40007 ear-72939A Arcal ear-72939A Arcal ear-72939A Arcal ear-72953A Arcal	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bur truck           ©7/27/2023           ©7/30/2023           Soft27/30/2023	D and Periods	seckidareas ESP32 GARGA-40027 Garch2934Acol	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           ©7/27/2023           ©7/27/2023           ©7/27/2023           ©           ©           0.7/27/2023           S           OT/27/2023           S           S           OT/27/2023           S           S           OT/27/2023           S           S           OT/27/2023           S <td>D and Periods</td> <td>spekAddress Es932 SARAA-40007 ear-72933Ascel ear-72933Ascel ear-72953Ascel</td> <td></td>	D and Periods	spekAddress Es932 SARAA-40007 ear-72933Ascel ear-72933Ascel ear-72953Ascel	
Come Nate & Nanyie Driver C Nopion Diplom Diplom Distance	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bur truck           ©7/27/2023           ©7/30/2023           sof 2023           sof 2023           ©           10-111           10-111           10-111           10-111           10-984           17-985           18-91           19-105           19-105           19-105           19-105           19-105	D and Periods	Services ESP32 4.747.04.4-0002 4.777.7573.4.4-001 4.7777573.4.4001	
Cicone Islaio & Manufe Oriver C Acquirel Copyon Tag C Islain Copyon Tag C Islain Copyon Tag C Islain Copyon	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Dur truck           ©7/27/2023           ©7/27/2023           ©7/30/2023           S of 2023           S of 2023           ©           10-111           16-222           07-864           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865           02-865 <tr< td=""><td>D and Periods</td><td>spekAddress Es932 SARAA-40007 ear-72933Asteal</td><td></td></tr<>	D and Periods	spekAddress Es932 SARAA-40007 ear-72933Asteal	
Diome Male & Manufe Diver D Acquist Deploy Tag D Manufe Ma	e Pate & Model detured (Next) 40 den Oate den Oate revert Date for word Date den for den for	T 1918.4 Hermathauit Joon JJ 2022 - 4-3 00 219 328 2022 - 4-3 00 219 328 2022 - 4-3 00 219 329 2022 - 5-3 00 229 700 2022 - 5-3 00 229 700 2023 - 5-4 00 229 700 2023 - 5-4 00 229 700			Type Yo Starting date Ending date submit	Bur truck           ©7/27/2023           ©7/30/2023           sof 2023           sof 2023           ©           10-111           10-111           10-111           10-111           10-984           17-985           18-91           19-105           19-105           19-105           19-105           19-105	D and Periods	Services ESP32 4.747.04.4-0002 4.777.7573.4.4-001 4.7777573.4.4001	

1 2 3 4

#### • Universal Reader Assistant (URA)

5 The reader software is developed based on the open-source program of Universal Reader Assistant (URA) provided by the manufacturer Thing Magic/Jadak (Figure 4A). The URA is an open-source 6 7 tag-reading application tool written in C# with the .Net framework. Using the open source codes, 8 we develop customized programs to implement our own user interface functionalities, including 9 (i) reading and displaying tag data (e.g., Electronic Product Code (EPC) (i.e., tag ID), timestamp, 10 source antenna, and received signal strength indication (RSSI)) on screen, (ii) writing custom EPC IDs to tags, (iii) retrieving data from the database and empowering the ability to modify assets's 11 12 data, and (iv) accepting multiple readers.

Figure 4. Graphic User Interfaces (GUIs) for RFID asset management

13

### 14 • Zebra Mobile Application

GUI for handheld readers is also programmed using the open-source code of ZebraRFID app (Figure 4B). We customize the source code design to enable database interaction, such as (i) retrieving tag data and information from the database, and (ii) updating tag information and synchronizing it with the database.

19

#### 20 • Database Connectivity and Synchronization

Both stationary readers and handheld RFID readers can save data locally or on a remote database server. The database design schema is shown in **Figure 5**. In the current database design, each

1 RFID tag is associated with exactly one traffic asset, such as a truck. One of the key considerations 2 in our system is to ensure uninterrupted operation even in the event of a temporary loss of internet 3 connectivity. To address this concern, the tag data is stored locally on the reader, allowing the 4 system to continue functioning even without internet access. Once the internet connection is re-5 established, the locally saved data is synchronized with the remote database, ensuring seamless 6 data transfer and continuity of operations. To facilitate communication between the application 7 and the remote database server, we have established REST API calls using the HTTP protocol. 8 This enables the various functionalities of the application to connect and interact with the remote 9 database as needed, ensuring efficient and reliable data management. 10 11

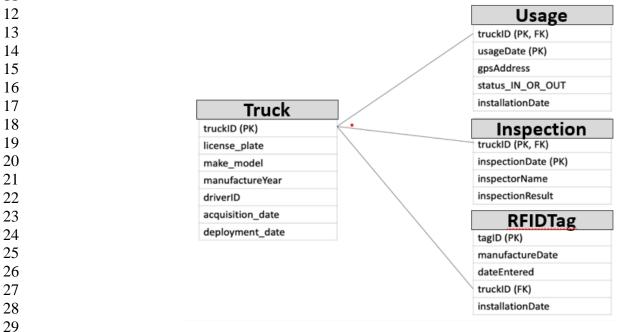


Figure 5. RFID asset management database scheme

33 The asset management database is designed using MySQL. For demonstration purpose, Figure 5 34 illustrates four tables created for specifically for managing trucks. These tables include: Truck, Usage, Inspection, and RFIDtag. The Truck table contains crucial information about the trucks 35 36 such as the license plate number, model, and driver details. Whenever an RFID reader detects a 37 tag mounted on the truck, the relevant information is automatically recorded and saved in the 38 UsageLog table. For stationary readers mounted at the garage entrance, the 'status\_IN\_OR\_OUT' 39 field is used to keep track of the truck's movement status, indicating whether it is entering or 40 leaving the garage. The Inspection table is responsible for storing the inspection history of the 41 trucks. Its attributes can be updated using either handheld readers or stationary readers. Lastly, the RFIDtag table serves as a repository for storing the unique tag Electronic Product Code (EPC) 42 assigned to each tag mounted on the asset item. This table ensures the accurate association of RFID 43 44 tags with their respective asset items in the system.

45

30

31 32 1 To facilitate secure and efficient database interaction, we have implemented a REST API protocol.

2 This protocol enables seamless communication between the database and other software

3 applications. The REST API ensures that data transfer between the database and the system is both

4 efficient and secure. By using the REST API, authorized software applications can easily access

5 and manipulate data stored in the database. This allows for real-time updates and retrieval of

6 information, enhancing the overall performance of the asset management system. Moreover, the
 7 REST API's security features ensure that only authenticated and authorized users can access

8 sensitive data, safeguarding the confidentiality and integrity of the information. Additionally, the

- 9 REST API's speed and efficiency enable rapid data transfer and processing, optimizing the
- 10 system's performance and responsiveness.
- 11

# 12 **RESULTS**

13 For performance evaluation and validation, we have set up the RFID system (Figure 6A) in the

14 Randolph Garage, which is owned by the Vermont Agency of Transportation and located in

15 Randolph, Vermont. This real-world test environment provides us with the opportunity to assess

16 the system's capabilities in a practical and operational setting.

17

18 In the experimental setup, a stationary RFID reader is installed at the entrance of the garage to 19 monitor the status of trucks – entering or departing the garage. In each truck, an RFID is attached 20 to the windshield. To ensure efficient detection of the trucks moving at different speeds and in 21 different directions, a 4-channel IZAR RFID reader is employed and configured with high 22 emission power (Figure 6B). The reader's antennas are strategically positioned. Antennas 1 and 4 23 are oriented outward, facing outside the gate, while Antennas 2 and 3 are directed towards inside 24 of the garage. In this configuration, when Antenna 1 or 4 detects RFID tags before Antenna 2 or 25 3, it indicates the truck is entering the garage, denoted as "IN" or "I". Conversely, if Antenna 2 or 3 detects RFID tags before Antenna 1 or 4, it indicates that the truck is exiting the garage, referred 26 27 to as "OUT" or "O". This systematic arrangement enables assets tracking based on the sequence 28 of RFID tag detections by the respective antennas.

29

30 Additionally, for the RFID readers to synchronize information with the central database, they need

31 to be connected to the internet. This connection can be established either through Wi-Fi or an

32 Ethernet cable. During the testing, a Wi-Fi extender is installed (Figure 6C) to ensure reliable

internet connectivity for the readers, thereby facilitating seamless data transmission to the database.

34 35

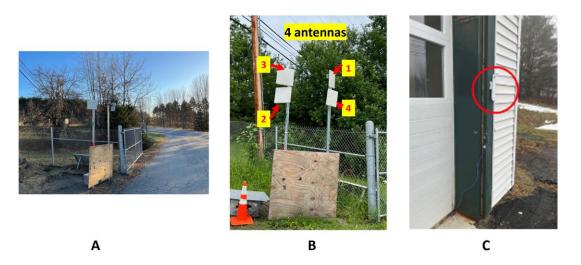


Figure 6. RFID system set up at the entrance of Randolph garage A. Garage entrance B. RFID reader with 4 antennas C. a Wi-Fi extender

2

1

3 Experimental Results

4 The system configuration, depicted in Figure 1, is successfully deployed in the field tests. This 5 configuration featured the modified Universal Reader Assistant (URA) operating under the 6 purview of the application server, which managed the incoming assets' information, regardless of 7 internet connectivity. When the application server is online, it promptly transmits the antenna 8 number that detects the RFID tag. In cases where internet connectivity is unavailable, the data is 9 securely stored in the local database and transmitted later when the internet connection is restored. 10 For enhanced RFID tag detection, the stationary Izar reader is employed with four antennas. These 11 antennas operate asynchronously to detect RFID tags, and the gathered data is then forwarded to 12 the application server for further processing.

13

29-165	2023-07-26 05:53:39	izar-7b7534.local	0
29-165	2023-07-26 06:52:02	izar-7b7534.local	0
29-165	2023-07-26 10:40:34	izar-7b7534.local	1
29-165	2023-07-26 12:04:31	izar-7b7534.local	0
29-165	2023-07-26 12:38:26	izar-7b7534.local	
29-165	2023-07-26 16:32:33	izar-7b7534.local	0
29-165	2023-07-27 05:57:54	izar-7b7534.local	1
29-165	2023-07-27 07:06:55	izar-7b7534.local	0
29-165	2023-07-27 12:10:53	izar-7b7534.local	I
29-165	2023-07-27 15:14:45	izar-7b7534.local	0
29-165	2023-07-27 15:44:57	izar-7b7534.local	1
29-165	2023-07-27 16:30:12	izar-7b7534.local	· · · · · · · · · · · · · · · · · · ·

- 14 15
- 16

17

Figure 7. A 2-day record of Truck 29-165 (dates: 07/26/2023-07/27/2023)

18 The results depicted in Figure 7 illustrate the dynamic status changes captured by the reader in two

19 days test (07/26/2023-07/27/2023). Within the GUI interface, one can easily view the truck ID,

20 corresponding timestamps, reader's name, and the status denoted by 'O' for 'Out' and 'I' for 'In'.

#### **Truck 29-165 Information**

Licens	se Plate	Make Model	Manufacture Year	Driver ID	Acquisition Date	Deployment Date
		GMC 2500 HD	2019		2019-02-04 00:00:00	2019-04-01 00:00:00

#### Figure 8. Truck 29-165's information

2

The data in Figure 7 highlights the notable activity of trucks 29-165, which stands as the most frequently tracked asset on the site. Clicking on the first column (29-165 in Figure 7) will lead to the page that shows the truck information as shown in Figure 8. Additionally, the final column in Figure 7 shows the repeated alternation between 'I' and 'O', clearly indicating the truck's consistent pattern of arrival and departure. Based on a two-day record, the system successfully identified the time of truck's arrival at the garage (indicated by a red square) and departure from the garage (indicated by a blue square) (Figure 8).

10

11 Nevertheless, it is worth noting that the system occasionally exhibits outliers, as shown by the two 12 rows marked with a yellow star on the right side of Figure 7. These outliers could be attributed to 13 various factors. For instance, in the case of the row with the first star, if multiple assets or trucks approach the reader in close-proximity, interference within that range might occur, leading to 14 certain vehicles not being detected by the reader. Such occasional incidents can be expected in 15 16 complex scenarios with dense asset movement, and they underscore the need to consider potential interference issues when analyzing the data obtained from the system. We will do further 17 18 investigations into this issue.

- 19
- 20 Handheld RFID reader

truckID	inspectionDate	inspectorName	inspectionResult
16-154	2023-07-29 17:54:17	Jay Hwasung Jung	RFID asset management handheld reader testing

#### Figure 9. Inspection example

21

As previously mentioned, the Handheld RFID reader fulfills essential functions, such as conducting inspections or adding new assets to the database. For demonstrative purposes, inspections were performed on one of the RFID tags, and the corresponding results are shown in Figure 9, presented as a database table named *Inspection*.

- 26
- To account for potential internet connectivity issues in the field, a practical functionality is integrated which allows the GUI to store the assets' information in the local database and allows

29 the asset manager to modify or input inspection information even without an internet connection

30 (Figure 10). Subsequently, the "Sync" option facilitates seamless synchronization with the central

31 database once an internet connection is re-established.

Rapid Read		Rapid Read	
TRUCK		TRUCK	
Truck ID:	56414F540000000000000000000000000000000000	Truck ID:	16-154
License Plate:		License Plate:	
Make & Model:		Make & Model:	Internatinoal
Manufactured (Year):		Manufactured (Year):	2000
Driver ID:		Driver ID:	
Acquisition Date:		Acquisition Date:	2022-12-20 02:19:28
Deployment Date:		Deployment Date:	2022-12-16 02:19:33
Tag ID:		Tag ID:	56414F540000000000000000000000000000000000
Manufacture Date:		Manufacture Date:	2022-12-20 22:37:00
Date Entered:		Date Entered:	2022-12-20 22:37:00
Installation Date:		Installation Date:	2022-12-20 22:37:00
Message:		Message:	found
INSPECTION			
Tag ID:	56414F540000000000000000000000000000000000	Tag ID:	56414F540000000000000000000000000000000000
Inspector Name:		Inspector Name:	Jay Hwasung Jung
Result:		Result:	RFID asset management handheid reader testing
		ing auni.	n nz azas management narwinaw reader testing

Figure 10. Results of sync the database on local device and the remote database server

1

#### 2 MFRC 522 RFID reader

```
Connected to WiFi network with IP Address: 10.0.0.3
Read personal data on a MIFARE PICC:
**Card Detected:**
Card UID: 8A 4A 8A 80
Card SAK: 08
PICC type: MIFARE 1KB
8A4A8A808a4a8a80
Name: DDDDDDDDDDDDDDDDDDDDDDDDDDDDD
**End Reading**
```

Figure 11. MFRC 522 RFID reader result

3

num	truckID	usageDate 🔻 1	gpsAddress	status_IN_OR_OUT
11345	10-111	2023-07-29 14:01:27	ESP32	1

4



5 The practicality of the proposed systems using different RFID readers, along with the viability of 6 a low-cost RFID reader, is examined through testing with the MFRC 522 RFID reader. Figure 11 7 depicts the process of the second proposed configuration (Figure 1B). Initially, the ESP 32 8 establishes a connection with the MFRC 522 RFID reader, which is then connected to the internet. 9 Subsequently, an RFID tag with a unique identifier (UID) of "8A4A8A80" is successfully detected. 10 Leveraging the REST API developed for this purpose, the detected information is seamlessly stored in the database, as shown in Figure 12. This experimentation validates the adaptability of 11 12 the proposed systems across different RFID readers and reinforces the potential for being 13 independent of constraints, such as cost.

#### 1 DISCUSSION

2 The system configuration proposed in this paper have a fundamental difference from the 3 previously suggested configurations [10]. Unlike the earlier ones, our configuration allows for the 4 deployment of multiple readers that can be managed within a single graphic user interface (GUI). 5 This capability of controlling multiple readers is crucial because it enables us to expand the system

6 to a state-wide level, efficiently managing assets across thousands of facilities. This scalability

- 7 makes our proposed configurations highly advantageous for large-scale asset management 8 applications.
- 9

10 The results of the proposed RFID asset management system offer valuable insights into its viability,

and reveal several factors that need to be considered for actual deployment: a) Internet connectivity. 11 12

The RFID readers need to establish connections with remote database server. It is important to 13 ensure the availability of internet connectivity where the RFID readers will be deployed. This may

14 involve setting up Wi-Fi network or utilizing other communication services, such as cellular

15 networks. b) Power Supply. The RFID system requires a constant and uninterrupted power supply

- 16 to maintain its operations. In the test scenario, the RFID reader was mounted next to the outdoor
- 17 garage gate, which was far from an indoor power supply. As a temporary solution, we used two
- rechargeable batteries that needed frequent swapping for recharging. For long-term deployment, a 18
- 19 more sustainable solution is to connect the system to the power grid or utilize large solar panels to
- 20 provide a reliable and continuous power source.
- 21

#### 22 **CONCLUSIONS**

23 In conclusion, this research demonstrated how RFID and wireless IoT technologies can be used 24 for efficient transportation asset management. Unlike traditional barcodes, RFID offers automation 25 and no need for direct visibility, making it a robust option for asset tracking. The experiments are 26 conducted for design validation. However, challenges like limited internet access in rural areas 27 and power supply need to be considered for practical implementation. Despite the challenges 28 encountered during the validation process, the proposed RFID asset management system 29 demonstrated its viability in real-time asset tracking and management, offering valuable insights 30 for transportation projects to make informed decisions. Future work in this area can concentrate 31 on further enhancing accuracy through the implementation of advanced methods such as Machine 32 Learning. Additionally, efforts can be made to increase the system's resilience in challenging environmental conditions. 33

34

35 By leveraging the potential of emerging technologies like RFID and IoT, this research paves the 36 way for significant improvements in transportation asset management practices. The integration 37 of RFID technology into transportation operations has the potential to enhance overall 38 sustainability and performance.. This research serves as a foundational stepping-stone towards the 39 adoption of innovative solutions for asset management in the transportation sector.

40

#### ACKNOWLEDGEMENT 41

42 The work presented in this paper is funded by the Vermont Agency of Transportation (Contract #: PS0894).

- 43
- 44
- 45 AUTHOR CONTRIBUTIONS

- 1 Tian Xia and Byung Lee lead the project as primary investigators making substantial contributions
- 2 to conception and design of the research. Jay Hwasung Jung and Wenzhe Chen are student research
- assistants developing system hardware and software programs and conducting laboratory and field
   tests.
- 4 5
- 6 **References:**
- S. Vama, "Executive Brief: Advancing a Transportation Asset Management Approach," 2021.
   [Online]. Available: <u>https://www.fhwa.dot.gov/asset/pubs/if12034.pdf</u>.
- Federal Highway Administration. (2013). AASHTO Transportation Asset Management Guide.
   (Report No. HIF13047). Retrieved from <u>http://www.fhwa.dot.gov/asset/pubs/hif13047.pdf</u>
- K. Deasy, R. Scott and C. Adams, "VAMIS Vermont Asset Management Information System," in Virtual Research & Innovation Poster Symposium, Vermont Agency of Transportation, 2020.
- S. Muthuramalingam, A. Bharathi, S. Rakesh Kumar, N. Gayathri, R. Sathiyaraj and B.
   Balamurugan, "IoT Based Intelligent Transportation System (IoT-ITS) for Global Perspective: A Case Study," in Internet of Things and Big Data Analytics for Smart Generation, vol. 154, Springer, Cham, 2018.
- PilComm, "Advantages of RFID Technology in Transportation," PilComm, Inc. Available: <u>https://www.piicomm.ca/advantages-rfid-technology-transportation/</u>.
- Yuan J, Jiang Y, Pan J. Design and Implementation of Data Center Asset Management System
   Based on RFID Technology. In International Conference on Autonomous Unmanned Systems
   2022 Sep 23 (pp. 3793-3801). Singapore: Springer Nature Singapore.
- 23 7. Casella G, Bigliardi B, Bottani E. The evolution of RFID technology in the logistics field: a
  24 review. Procedia Computer Science. 2022 Jan 1;200:1582-92.
- 8. Tripathi A, Dadi GB, Nassereddine H, Sturgill RE, Mitchell A. Assessing Technology Implementation Success for Highway Construction and Asset Management. Sensors. 2023 Mar 31;23(7):3671.
- W. Chen, J. Childs, S. Ray, B. S. Lee and T. Xia, "Integrating In-Vehicle and Handheld RFID Readers for Developing Traffic Signage Inventory Management System in Rural and Urban Environments," in Transportation Research Bureau (TRB), Washington, D.C., 2020.
- 10. W. Chen, J. Childs, S. Ray, B. Lee, T. Xia, "RFID Technology Study for Traffic Signage
   Inventory Management Application," *IEEE Transactions on Intelligent Transportation Systems, Vol. 23, Issue 10. pp. 17809-17818, October 2022.*
- 11. T. Xia and B. S. Lee, "Radio Frequency Identification (RFID) Technology for Transportation
   Signage Inventory Management," in Virtual Research & Innovation Poster Symposium,
   Vermont Agency of Transportation, 2020.
- 12. Álvarez López Y, Franssen J, Álvarez Narciandi G, Pagnozzi J, González-Pinto Arrillaga I,
  Las-Heras Andrés F. "RFID Technology for Management and Tracking: e-Health Applications.
  Sensors (Basel)". 2018 Aug 13;18(8):2663. doi: 10.3390/s18082663. PMID: 30104557;
  PMCID: PMC6111728.
- 41 13. Lampe, M., Strassner, M., Fleisch, E. RFID in Movable Asset Management. In: Roussos, G.
   42 (eds) Ubiquitous and Pervasive Commerce. Computer Communications and Networks.
- 43 Springer, London. <u>https://doi.org/10.1007/1-84628-321-3\_4</u>, 2006