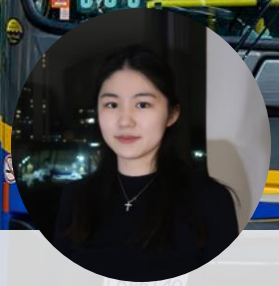
Source: TransLink 2023 Bus Speed and Reliability Report

Transforming TransLink For A Future Of Smart Transportation



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Presented by: Transcend Consulting [Team 10]
Date: November 16, 2023
Deloitte ThinkTECH 2023

Transcend Consulting

TRANS LINK Deloitte. thinkTECH

Executive Summary

Context

TransLink has been continuously improving its transportation services in Metro Vancouver with diverse initiatives.

However, **customer satisfaction is significantly affected by delays** in transit services

.

TransLink must **drive ambitious technological innovations** across its services to **revolutionize transit operations** and **meet customers' most fundamental needs.**

Key Question

How can TransLink leverage Big Data and cutting-edge technological advancements to enhance the **timeliness and reliability** of public bus services and directly **improve customer experience**?

Strategy

Green Means Go

Prevent bus delays by giving Traffic Signal Priority to TransLink buses	Deploy Intelligent Transport Technology for TransLink vehicles and traffic signals	Partnerships with key stakeholders to pilot project

Impact

Prevent bus delays and save delay costs by approximately 50% in five years	Successfully implement TSP technologies within 5 years	Gain approval to deploy project across 3+ municipalities

Bus Commutes: A Critical Influence on Transit Experience

Despite TransLink's real-time data and trip planning tools, external traffic conditions lead to bus delays and alter customer's transit journey

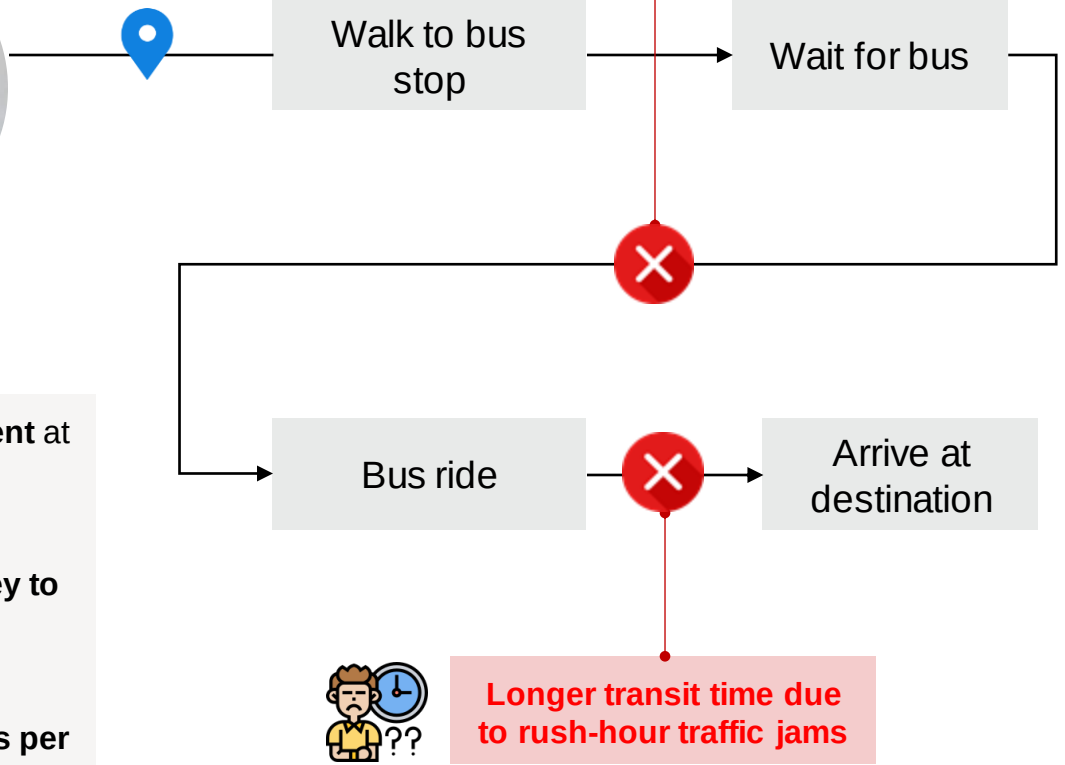
Juliana

Undergraduate student at UBC

Commutes from **Surrey to UBC** 3-4 times/week

Transit time: **1.5 hours per one-way trip**

2 bus rides, 1 SkyTrain ride



A 5-minute bus delay can extend Juliana's transit time to 2 hours

Commuters like Juliana face extended transit times, despite having trip planning tools.

Traffic conditions and delays affect the satisfaction and transit time of TransLink customers.

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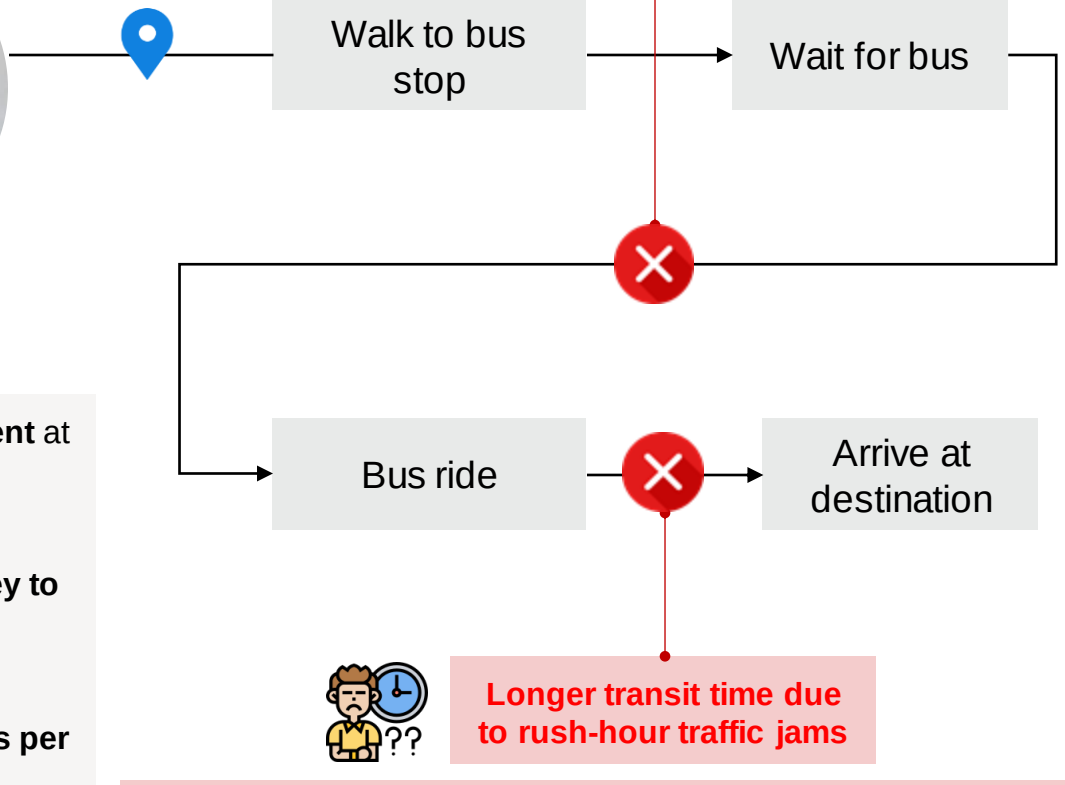

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Critical Impact: Bus Delays on Customer Experience and Operational Expenses

Bus delays and cancellations are a misalignment with TransLink's Timely and Reliable priority

Buses are TransLink's major customer touchpoint

Experience before & during bus rides can affect customers' satisfaction with TransLink services

63% of transit journeys are by bus

60% of travellers are carried by buses during peak times

The focus on reliable buses is essential to **ensure a strong foundation for TransLink**

High costs of bus delays

Tangible costs of delay due to traffic

$2M-7M increase in annual operating costs

20% time penalty for riders and drivers

Intangible costs of delays

- Job security and personal livelihood
- Lower trust in using TransLink buses
- Customers switch to personal vehicles

Improving buses' timeliness and reliability is a crucial priority to enhance **customer** experience, protect TransLink's **reputation** and avoid rising operating **costs**

Traffic congestion is the main cause of bus delays

Rapid buses can still be slowed down by traffic

Traffic congestion may vary

→ **Difficult to simply optimize schedule based on past data**

More initiatives are needed to fully 'protect' buses from traffic congestions

Source: TransLink 2023 Bus Speed and Reliability Report

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Tangible costs of a 10-minute delay due to traffic

Traffic congestion is the main cause of bus delays

Rapid buses can still be slowed

TransLink needs to ensure the reliability and timeliness of buses by reducing delays caused by traffic congestions, which will directly contribute to better customer experience, positive brand image and long-term sustainability for public transit operations

- Lower trust in using TransLink buses
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Green Means Go

Alternatives Matrix of TSP Over Other ITS Solution

	Traffic Signal Priority	Predictive Maintenance	Real-time Travel Assistance Features	Partnerships for Multimodal Services	Car Parking App near Transit Stations
Innovation	✓	✓	●	✓	●
★ Operational Stability (i.e. bus delays)	✓	✓	✗	✗	✗
★ Customer Reach	✓	●	●	●	✗
Ease of Implementation	●	●	✓	●	✓

Traffic Signal Priority (TSP) For TransLink Buses As A Mitigation To Congestions

Bus delays can be prevented by giving priority of green traffic signal to buses during peak hours

Key Objective: Reduce bus delays by giving traffic signal priority to TransLink buses during peak-hour traffic jams

TSP system allows TransLink to align with its Timeline and Reliable core value

Without TSP System

Customers are **frustrated** when buses are caught in traffic and delayed.

With TSP System

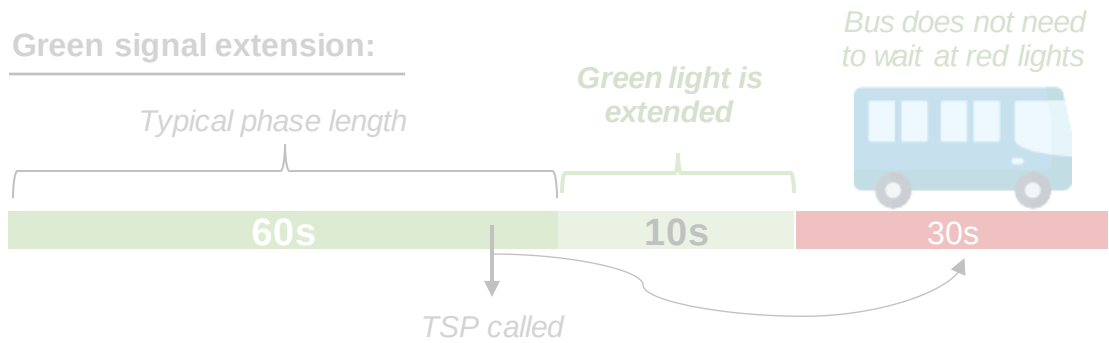
Significant **tangible benefits** to customers
Clearly **show** TransLink's improvement efforts

Traffic lights dynamically adjust for TransLink buses that may be running late

Bus approaches during a red light
→ TSP system **gives an early green**

Bus approaches during a green light
→ TSP system **extends green signal time**

Reduce wait times at traffic lights



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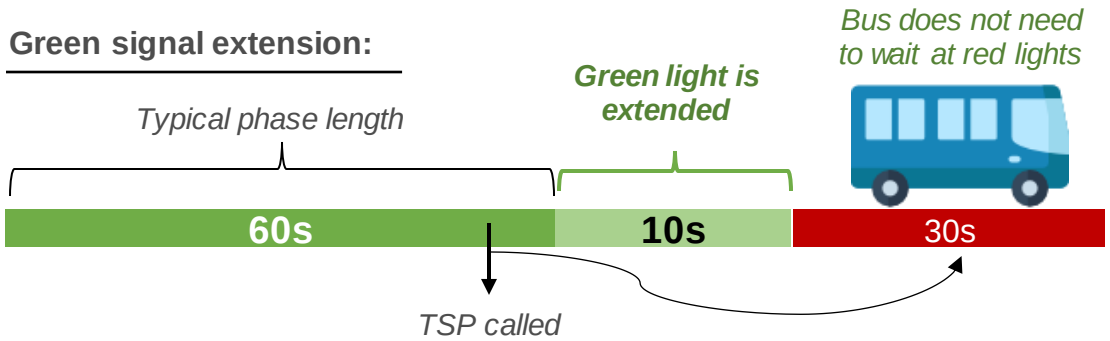

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Similar traffic signal priority projects have been successfully piloted in other regions, including New York City

Since 2012, The New York City Department of Transportation (NYC DOT) and the Metropolitan Transportation Authority (MTA) have ***been implementing TSP on busy bus routes in NYC****, to* ***reduce the time buses are stopped at traffic lights.***

Project Overview

Scale
1,382 intersections on 5+ bus routes

Measures of Success
- Reduced bus travel times during peak commuting period
- Increase in bus ridership

Collaboration
- Transportation department (city's traffic infrastructure)
- Public transportation corporation (install technology on buses)

Main Technology Infrastructure

Bus GPS tracking & Traffic Lights optical detector devices
Detect incoming buses at intersections to trigger request

MTA's Bus Command Center
TSP request is sent via bus command center to Traffic Management Center

TMC uses New York city Wireless Network to communicate with traffic signal controllers
Decision to grant bus traffic signal priority is sent from TMC to modify signal timing at intersections

Impact

Lower bus times by a daily average of 18%

Save travel time by 5-30% for commuters

Enhance benefits of other bus speeds measures (e.g. dedicated bus lanes)

Increase bus ridership by 10%

Source: DOT Releases Status Report on "Transit Signal Priority" Technology Used To Speed MTA Buses

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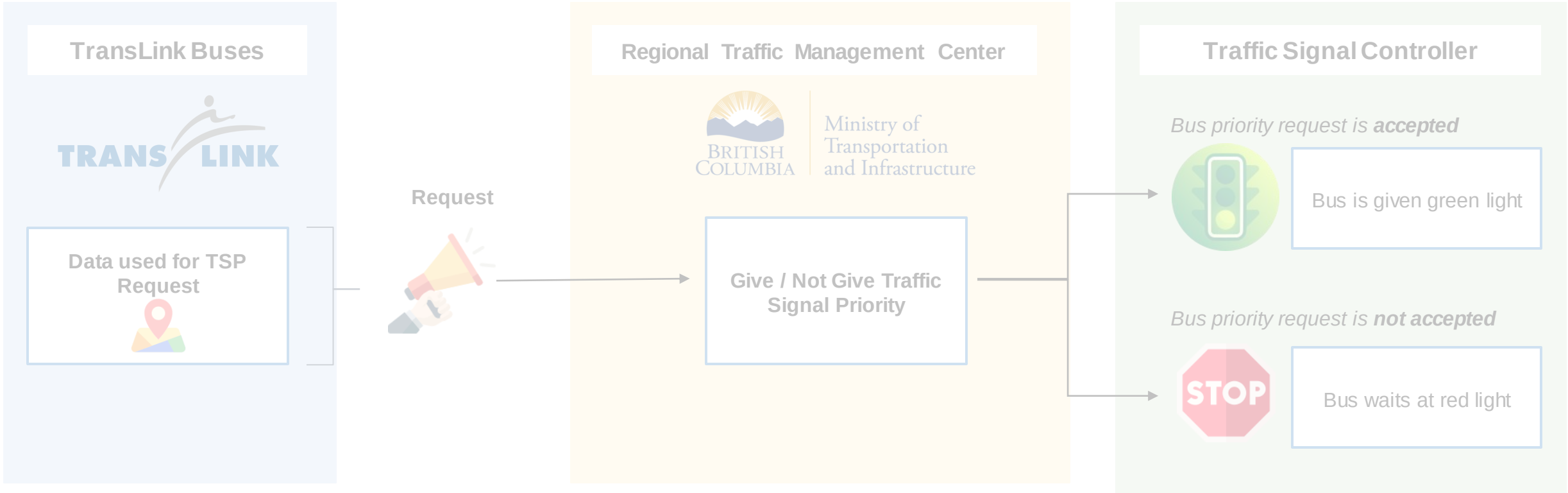
Green Means Go

Implementing Intelligent Transport System for Optimized Traffic Signal Priority

A high-level overview of the signal priority process

Key Objective: Design an efficient process and system architecture that can seamlessly integrate with TransLink's and the city's existing systems



The TSP Project is enabled by the communication of data between 3 key systems: TransLink Buses, traffic management center, and traffic signals

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TransLink Buses

TRANSLINK

TransLink API Package

Data used for TSP Request

TSP Request

Regional Traffic Management Center

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

Give / Not Give Traffic Signal Priority

Traffic Signal Controller

*Bus priority request is **accepted***

Bus is given green light

*Bus priority request is **not accepted***

Bus waits at red light

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The Green Means Go project implements algorithm that let TransLink **satisfy key stakeholders and significantly improve customers' transit experience**

TransLink Buses

TRANSLINK

TransLink API Package

Data used for TSP Request

Request

Innovate using existing data that can be collected from buses' GPS & Radar

Regional Traffic Management Center

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

Traffic Signal Priority

Traffic Signal Controller

*Bus priority request is **accepted***

Bus is given green light

*Bus priority request is **not accepted***

STOP

Bus waits at red light

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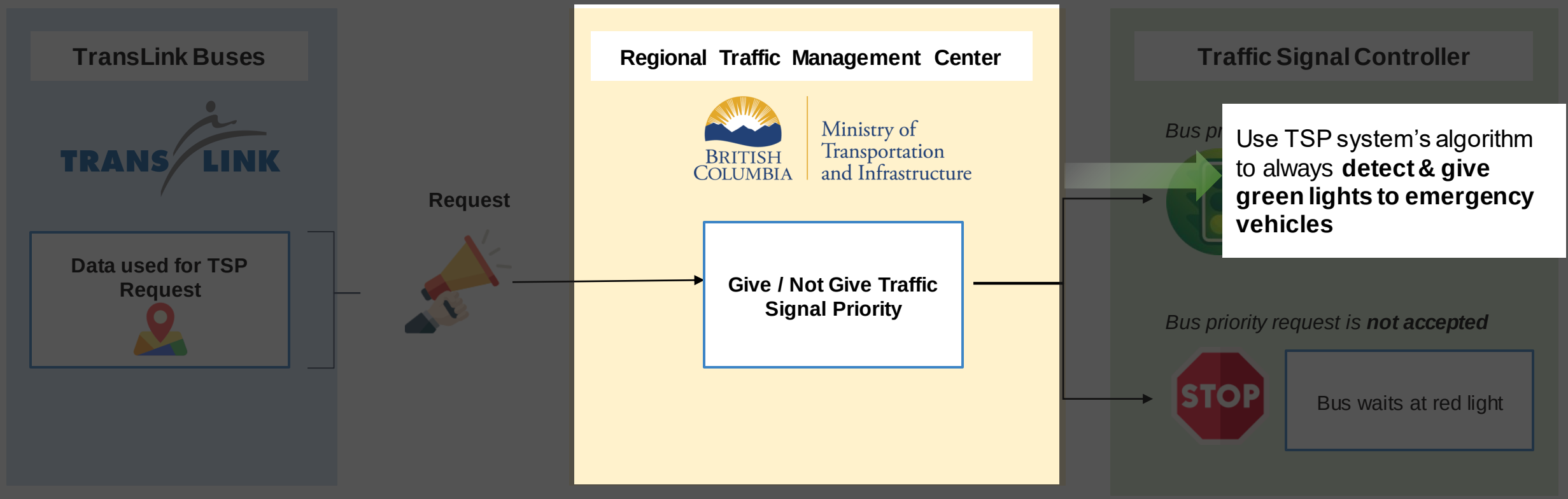

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Request

Regional Traffic Management Center

Achieve TransLink's **Timeliness & Reliability** core values by minimizing customers' bus ride times

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Overview of 3 Key Actors

A high-level overview of the Traffic Signal Priority process

Key Objective: Design an efficient process and system architecture that can seamlessly integrate with TransLink's and the city's existing systems

TSP system utilizes 3 key existing infrastructure	Each existing infrastructure plays different functional roles
TransLink buses with existing & new hardware (GPS, Routers, Radar...)	Transmit data about bus location and surrounding traffic for traffic signals to detect.
British Columbia's **Regional Traffic Management Center**	Real-time algorithm to automatically **process buses' requests** and **control traffic signals**
Traffic signal controllers (with cameras, sensors)	• **Detect** oncoming buses • **Send TSP requests** to traffic management center • **Modify traffic signals** for buses or emergency vehicles

The TSP Project is enabled by the communication of data between 3 key systems: TransLink Buses, traffic management center, and traffic signals

Prototype

TSP System requires a clear architecture framework to facilitate data flow

What technologies will enable the communication of data between different systems?

Wireless communication technology

Buses can communicate with other vehicles / infrastructure technology

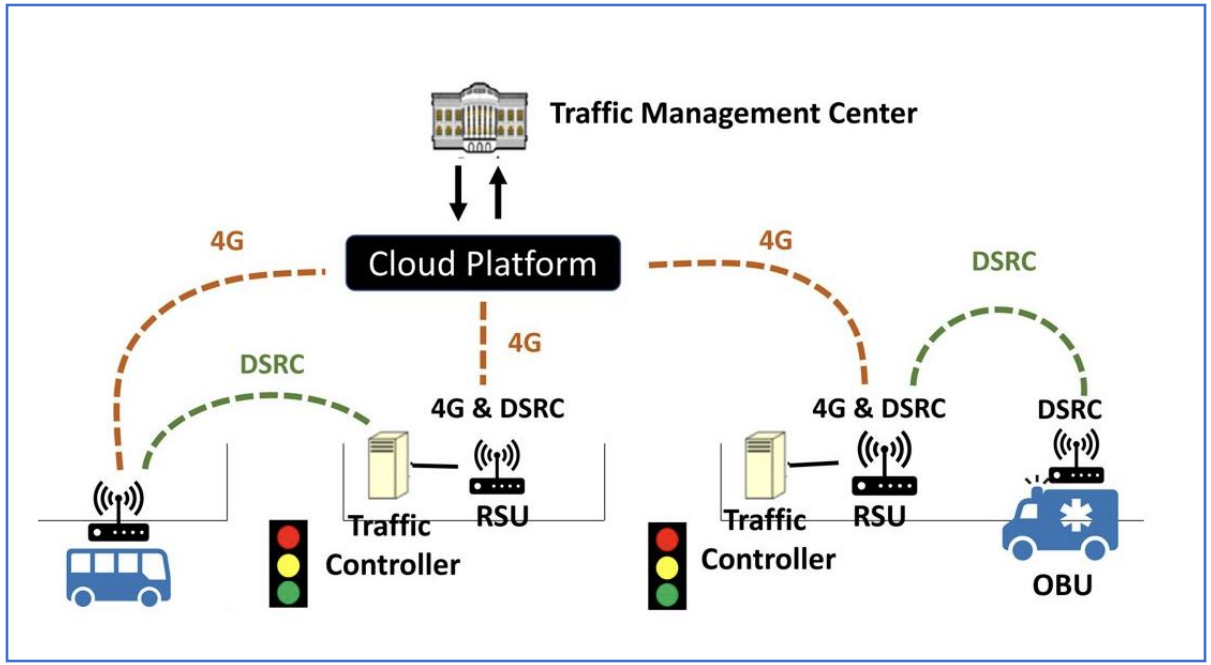
Wi-Fi

Real-time communication with cloud servers
→ Ensures **timely updates and information exchange.**

Dedicated short-range communication (DSRC)

Well suited for fast moving dynamic environment (TransLink bus)

System Framework



TSP simulation using SUMO (Simulation Of Urban Mobility)

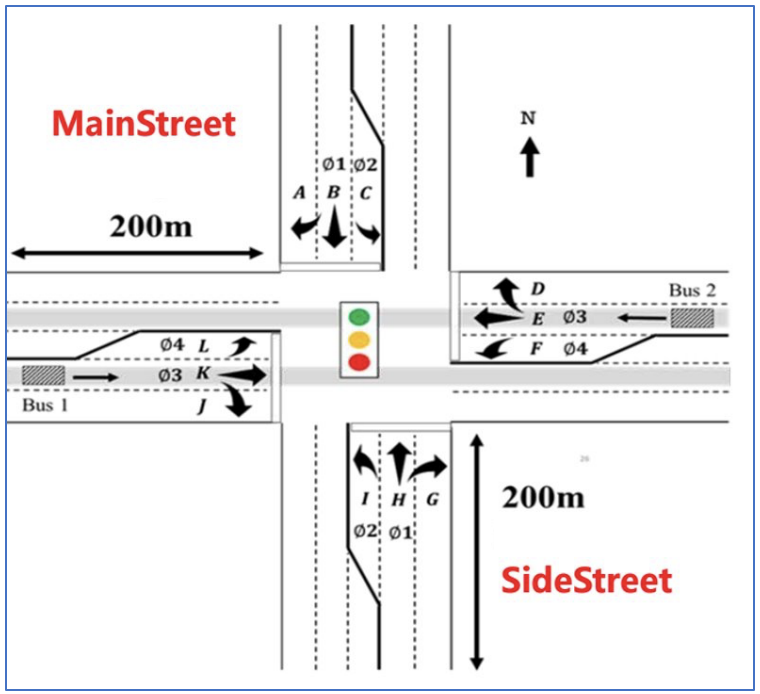
An In-depth Analysis Using SUMO Simulation In A Real-world Scenario

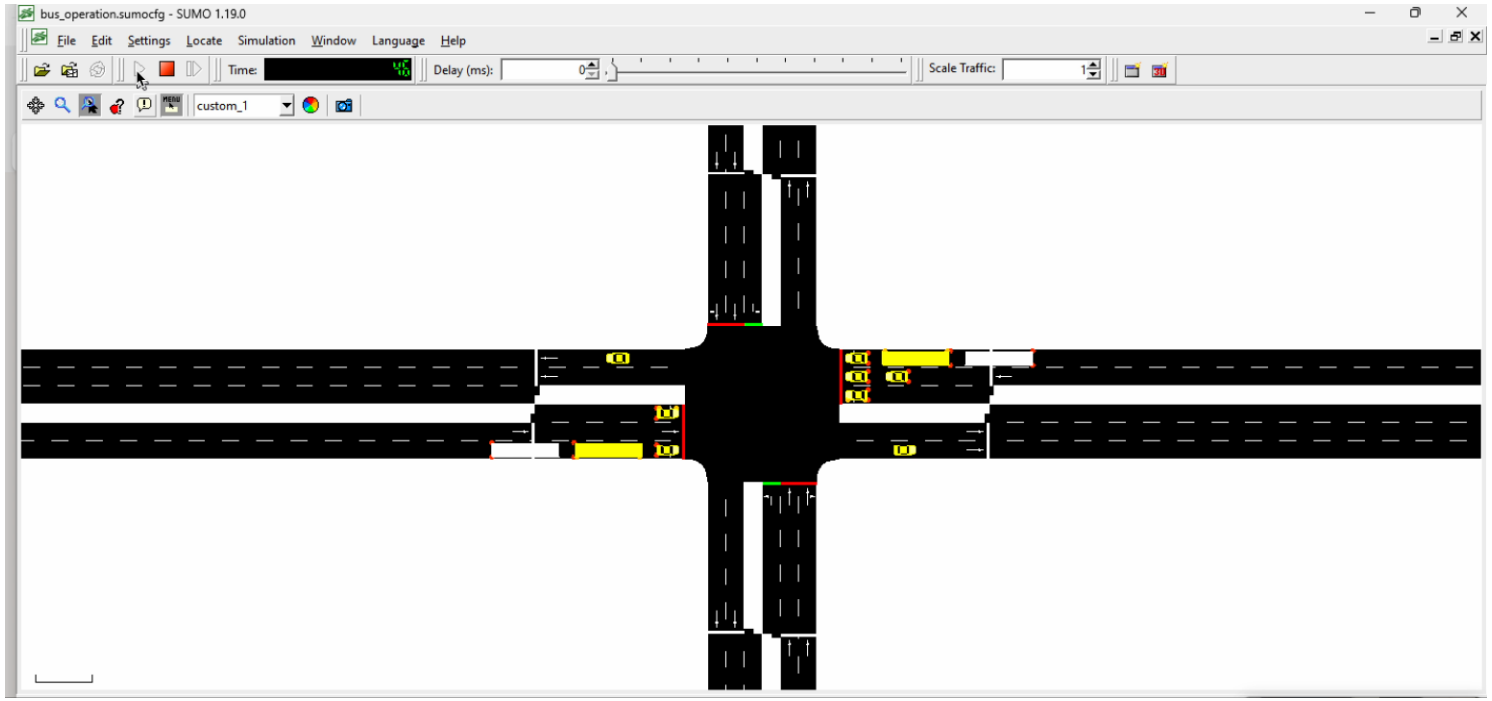
Simulation Overview

Simulation considered the following traffic condition

A single intersection

2 – 3 lanes per roadway





Simulation shows that the TSP system reduces waiting count and travel time

Result of Simulation: The TSP system effectively reduces bus delays as planned

TSP algorithm is tested on 7 groups (21 intersections)

All observations show lower travel time

Results of each intersection group

Group 1	Waiting count	Travel time
Fixed	4.67	196.00
Mixed	2.00	175.17
	-57%	-11%

Group 3	Waiting count	Travel time
Fixed	0.67	58.83
Mixed	0.33	43.67
	-50%	-26%

Group 5	Waiting count	Travel time
Fixed	0.50	47.60
Mixed	0.05	42.21
	-90%	-11%

Group 7	Waiting count	Travel time
Fixed	2.17	179.17
Mixed	0.83	142.21
	-62%	-21%

Group 2	Waiting count	Travel time
Fixed	1.33	105.67
Mixed	0.67	95.67
	-50%	-9%

Group 4	Waiting count	Travel time
Fixed	0.67	76.17
Mixed	0.34	65.43
	-50%	-14%

Group 6	Waiting count	Travel time
Fixed	0.83	87.83
Mixed	0.33	65.43
	-60%	-26%

	Waiting count	Travel time
Avg	-60%	-16%

Source:

Simulation shows that the TSP system reduces waiting count and travel time

Result of Simulation: The TSP system grants buses' signal priority requests and effectively reduces bus delays as planned

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Group 4		Travel time
Fixed		87.83
Mixed		65.43
		-26%

- **60% reduction** in buses' waiting count
- **16% reduction** in buses' travel time

	Waiting count	Travel time
Avg	-60%	-16%


Green Means Go

Forging Collaborative Partnerships: TransLink's Green Means Go Initiative with Key Stakeholders

Approval to implement technology on city's road infrastructure is required from local, municipal and regional governments in Metro Vancouver

Key Objective: How can TransLink involve key stakeholders to gain approval for the Green Means Go project?

TransLink needs to consult with the following groups

- BC Ministry of Transportation and Infrastructure
- Mayors' Council on Regional Transportation
- Metro Vancouver Regional District
- Mayors' Council on Regional Transportation (Municipalities where the TPS system will be deployed)
- The public in the transportation service region

Green Means Go project requires high coordination between TransLink and municipalities

TRANSLINK

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

- Steering committee, in-house project team
- Acquire, install, maintain vehicle devices for TPS system

BC MTI and **all impacted municipalities:**

- Control the programming of traffic signals
- Acquire, install, maintain TSP devices at intersections

Source: CRD REPORT TO THE TRANSPORTATION SELECT COMMITTEE

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Key Objective: How can TransLink involve key stakeholders to gain approval for the Green Means Go project?

TransLink needs to consult with the following groups

- BC Ministry of Transportation and Infrastructure
- Mayors' Council on Regional Transportation
- Metro Vancouver Regional District
- Mayors' Council on Regional Transportation (Municipalities where the TPS system will be deployed)
- The public in the transportation service region

Green Means Go project requires high coordination between TransLink and municipalities

- Steering committee, in-house project team
- Acquire, install, maintain vehicle devices for TPS system

BC MTI and **all impacted municipalities:**

- Control the programming of traffic signals
- Acquire, install, maintain TSP devices at intersections

Source: CRD REPORT TO THE TRANSPORTATION SELECT COMMITTEE

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Conduct public consultation and analyze data to understand locations to pilot the project

Online survey for public opinions on giving buses traffic signal priority:
- Customers' experience with bus delays
- Customers' common bus routes

Analyze existing data to determine appropriate locations for pilot:
- Number of bus delays, classified by time periods within a day
- Bus routes with the most delays
- Municipalities with the most delays (e.g. Vancouver vs. Burnaby)

Present a concrete proposal & business case report to stakeholders:
- Pilot project in municipalities with medium and high bus delays
- Present business case with project roadmap and benefits

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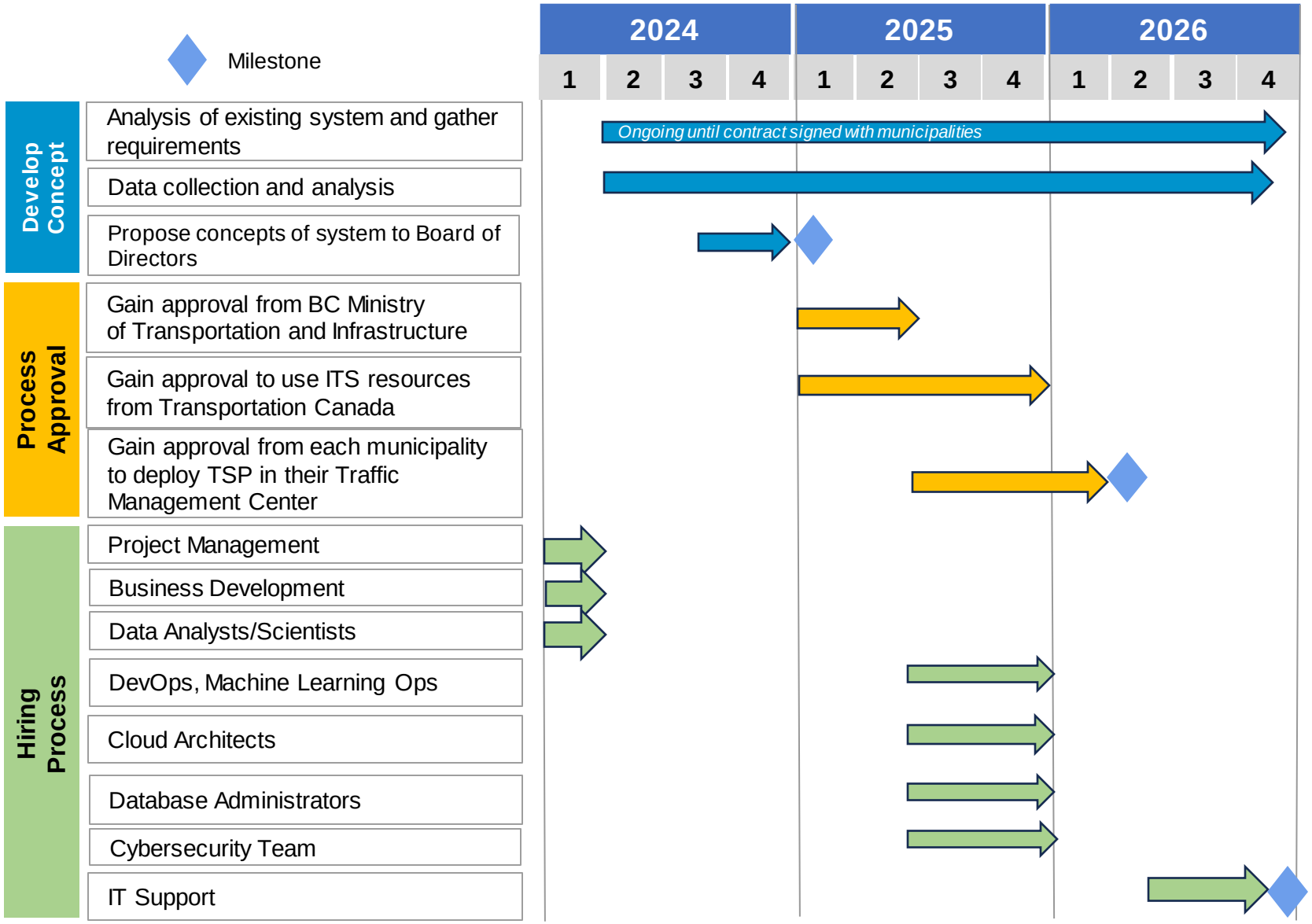
Present a concrete proposal & business case report to stakeholders:
- Pilot project in municipalities with medium and high bus delays
- Present business case with project roadmap and benefits
- Utilize change management model to gain stakeholders' buy-in

Source: CRD REPORT TO THE TRANSPORTATION SELECT COMMITTEE

Implementation

Green Means Go Project: 5-Year Implementation Roadmap



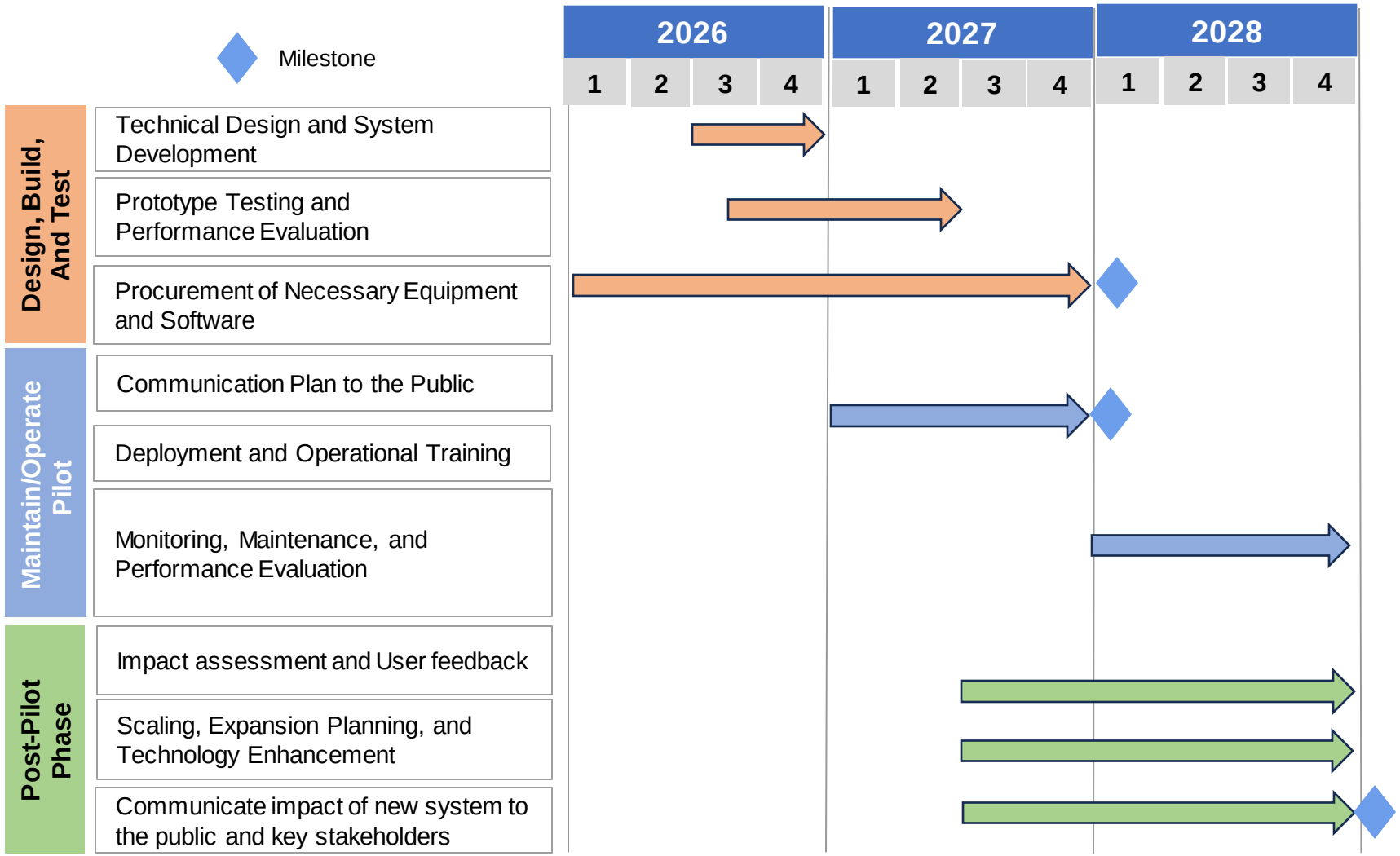
KPIs

- **90% on-time rates** for buses in routes with TSP system
- **90% customer satisfaction** rate for bus services
- **20%** increase in **bus ridership**

Milestones

- Board of Directors' approval by Q4/2024
- Deploy TSP system in 2+ municipalities by Q2/2026
- Hire full project team by Q4/2025

Green Means Go Project: 5-Year Implementation Roadmap



KPIs

- **90% on-time rates** for buses in routes with TSP system
- **90% customer satisfaction** rate for bus services
- **20%** increase in **bus ridership**

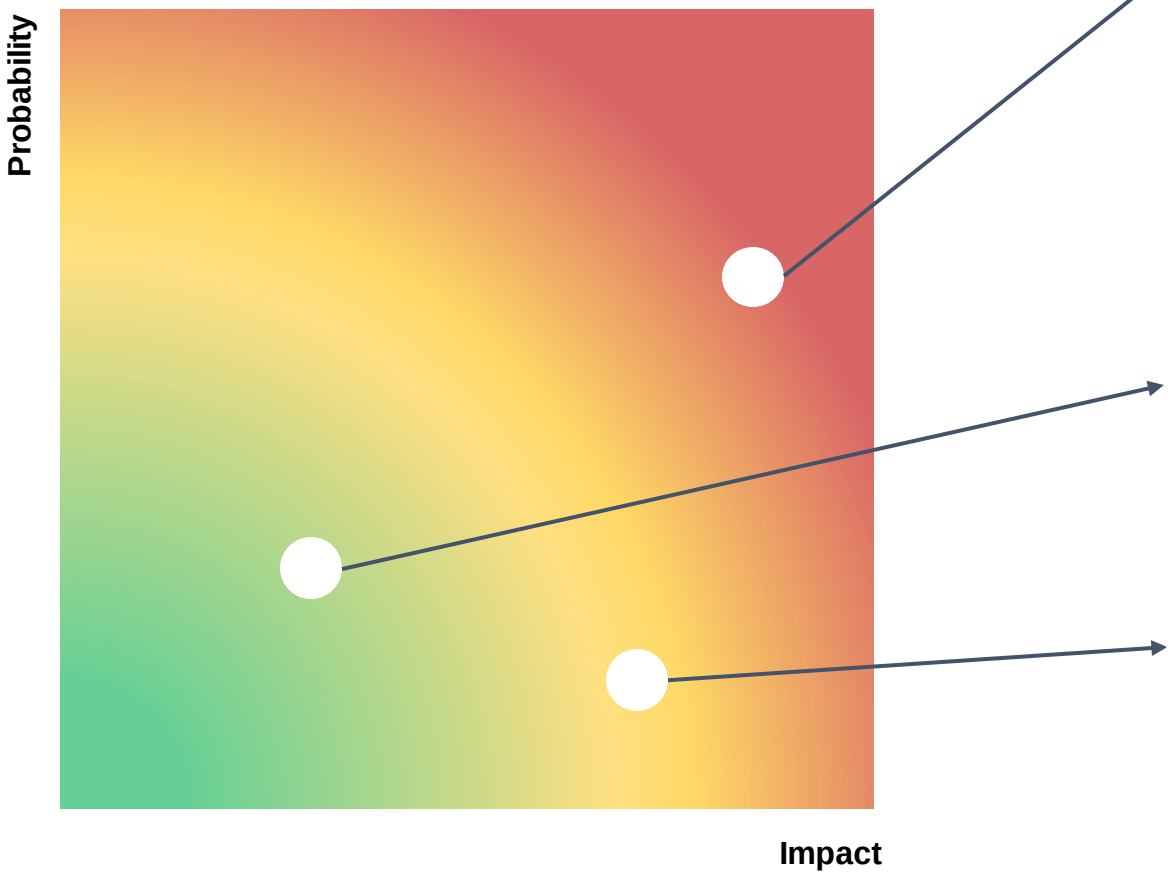
Milestones

- Procure and install all necessary hardware & software by Q1/2028
- Pilot testing of TSP in chose corridors by Q3/2027
- Full deployment of TSP and maintenance by Q4/2028

Organizational Reporting Structure For Operational Excellence

- Project Management
  - Cloud Architects
  - Business Development
    - Data Analysts
    - Data Scientists
    - Business Analysts
  - Executive Leadership
    - DevOps, MLOps
    - DBA
  - IT Leadership/Infrastructure Manager
    - IT Support
    - Cybersecurity

Risks & Mitigation



1 Lack of buy-ins from some municipalities

Pilot TSP system in approved municipalities

Continue to use change management framework to work closely with and negotiate with each municipality representative individually.

2 Real-time data from buses' GPS are not accurate

Use Location-based Service tracking system instead of GPS.

3 Lack of compliance with strict municipalities' data regulations

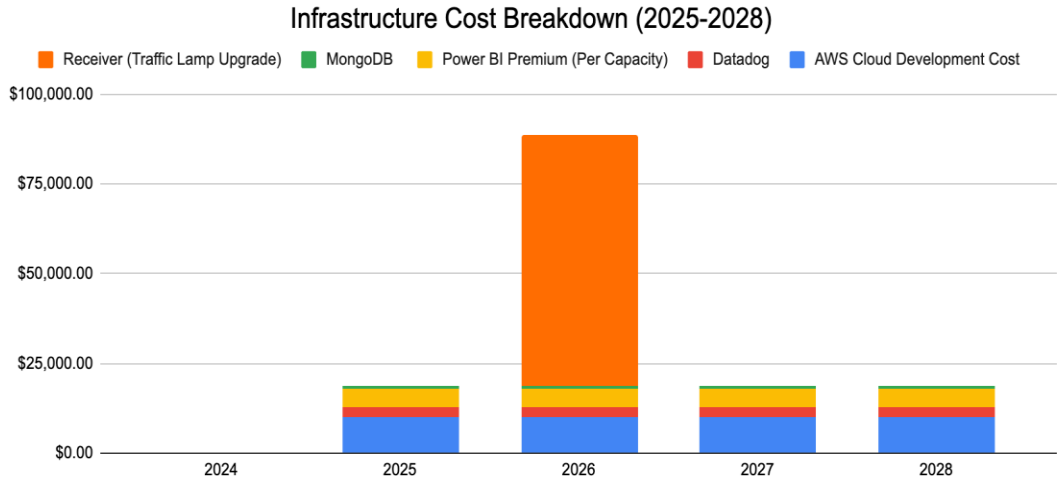
Implementation timeline needs to require continuous monitoring post-implementation

Project team hires well-trained cybersecurity experts to prevent miscompliances.

Impact Analysis

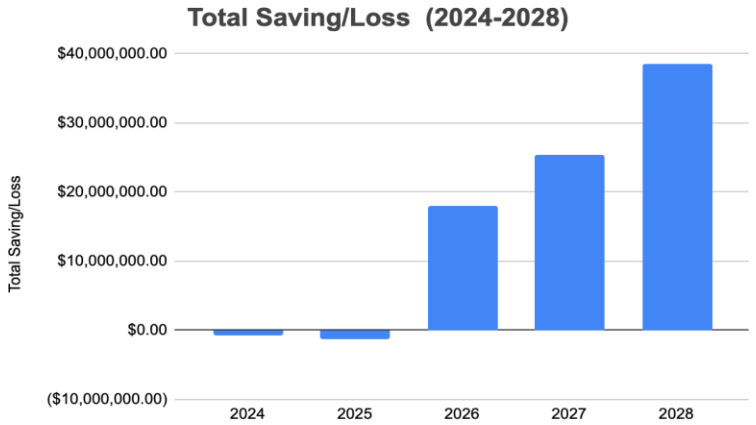
With investment in the initial phase, TSP improves efficiency and customer satisfaction in the long term.

Key Assumptions



Over $80 million of costs (800,000 annual service hours), are caused by roadway delays per year.

Key Results



Over the Five Years:

PV (Total Cost) = $6.9 M
PV (Total Savings) = $70 M

Positive NPV of $63 M

Long term Efficiency:

1. Improved Customer Satisfaction & Safety
2. Initial Investment to Eradicate Bus Delays
3. Significant Financial and Intangible Return on Investment

Source: TransLink 2023 Bus Speed and Reliability Report

Green Means Go Project Allows Higher Customer Satisfaction From Regular Commuters

TransLink's real-time data and Transit Signal Priority approach lead to improved customer's transit journey

Juliana

Undergraduate student at UBC

Commutes from **Surrey to UBC** 3-4 times/week

Transit time: **1.5 hours per one-way trip**

2 bus rides, 1 SkyTrain ride

Corrected wait time as buses are not delayed

Walk to bus stop → Wait for on-time bus → Bus ride → Arrive at destination

Improved transit time due to Traffic Signal Priority during peak hours and traffic congestion

By implementing Traffic Signal Priority system to give buses priority, TransLink can ensure **correct wait times and improved transit time for all customers.**

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Executive Summary

Context

TransLink has been continuously improving its transportation services in Metro Vancouver with diverse initiatives.

However, **customer satisfaction is significantly affected by delays** in transit services

.

To further prioritize customer experience, TransLink must **drive ambitious technological innovations** across its services to **revolutionize transit operations** and **meet customers' most fundamental needs.**

Key Question

How can TransLink leverage Big Data and cutting-edge technological advancements to enhance the **timeliness and reliability** of public bus services and directly **improve customer experience**?

Strategy

Green Means Go

Prevent bus delays by giving Traffic Signal Priority to TransLink buses	Deploy Intelligent Transport Technology for TransLink vehicles and traffic signals	Partnerships with key stakeholders to pilot project

Impact

Prevent bus delays and save delay costs by approximately 50% in five years	Successfully implement TSP technologies within 5 years	Gain approval to deploy project across 3+ municipalities

Appendix

Appendix

Problem Identification & Analysis

Green Means Go

Prototype

Implementation

Appendix

Traffic Signal Priority (TSP) achieves TransLink's core value

*Bus delays are **directly** associated with customer satisfaction and personal livelihoood*

TSP system aligns with TransLink's Core values

Travel Time:
Minimal delay from traffic congestion

Reliability:
Buses operate on schedule, consistent throughout the day

Customer Experience:
On-time buses make transit services easier to use

Safety:
Control of traffic signals allow enhanced safety for pedestrians

Green Means Go is an ambitious project and worthwhile to implement

Enhanced personal livelihood and job security for transit customers

Save $80 million in annual bus delays costs (2021)

Piloted and successfully implemented by multiple regions (NYC, California,…)

Key measures of success: Higher customer satisfaction, less customer complaint, enhanced reputation

Green Means Go is an ambitious, worthwhile project that can sustain long-term growth for the transit system and bring tangible benefits to TransLink's customers

Source

Overview of 3 Key Actors

A high-level overview of the Traffic Signal Priority process

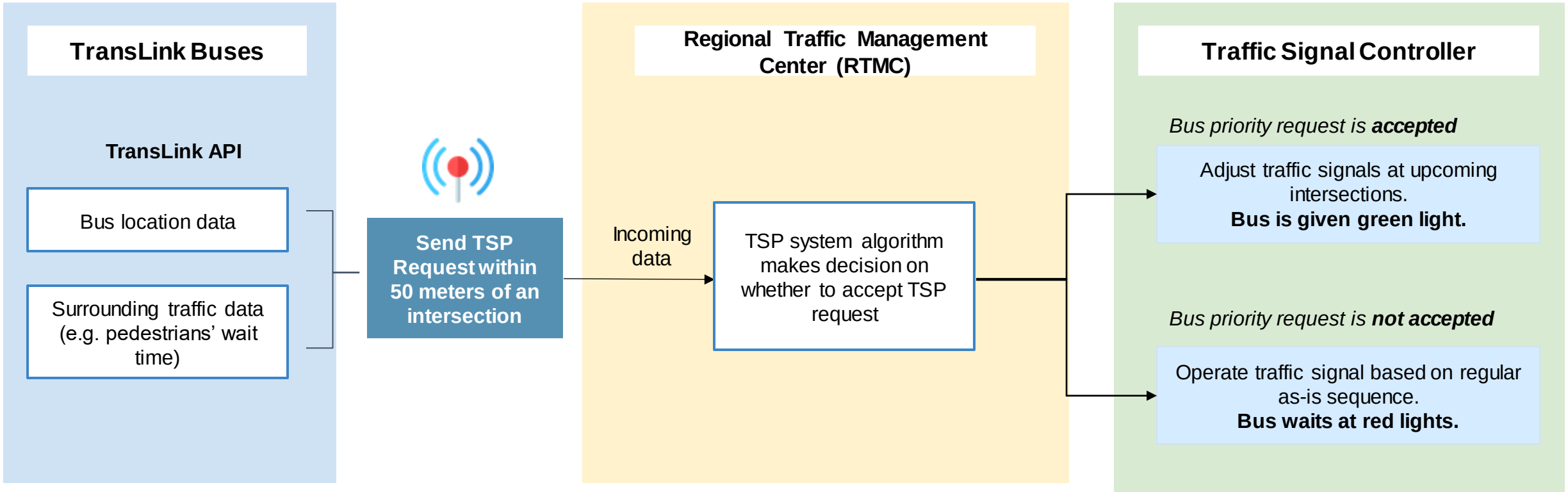
Key Objective: Design an efficient process and system architecture that can seamlessly integrate with TransLink's and the city's existing systems

TSP system utilizes 3 key existing infrastructure	Each existing infrastructure plays different functional roles
TransLink buses with existing & new hardware (GPS, Routers, Radar...)	Transmit data about bus location and surrounding traffic for traffic signals to detect.
British Columbia's **Regional Traffic Management Center**	Real-time algorithm to automatically **process buses' requests** and **control traffic signals**
Traffic signal controllers (with cameras, sensors)	• **Detect** oncoming buses • **Send TSP requests** to traffic management center • **Modify traffic signals** for buses or emergency vehicles

The TSP Project is enabled by the communication of data between 3 key systems: TransLink Buses, traffic management center, and traffic signals

TSP System Data Flow

The TSP System utilizes Vehicle-to-Everything (V2X) Technology to capture data and communicate between different traffic systems



TSP System requires a clear architecture framework and efficient data flow process

An efficient data flow diagram allows TransLink to leverage data and the TSP system to be optimized

Data Flow Process

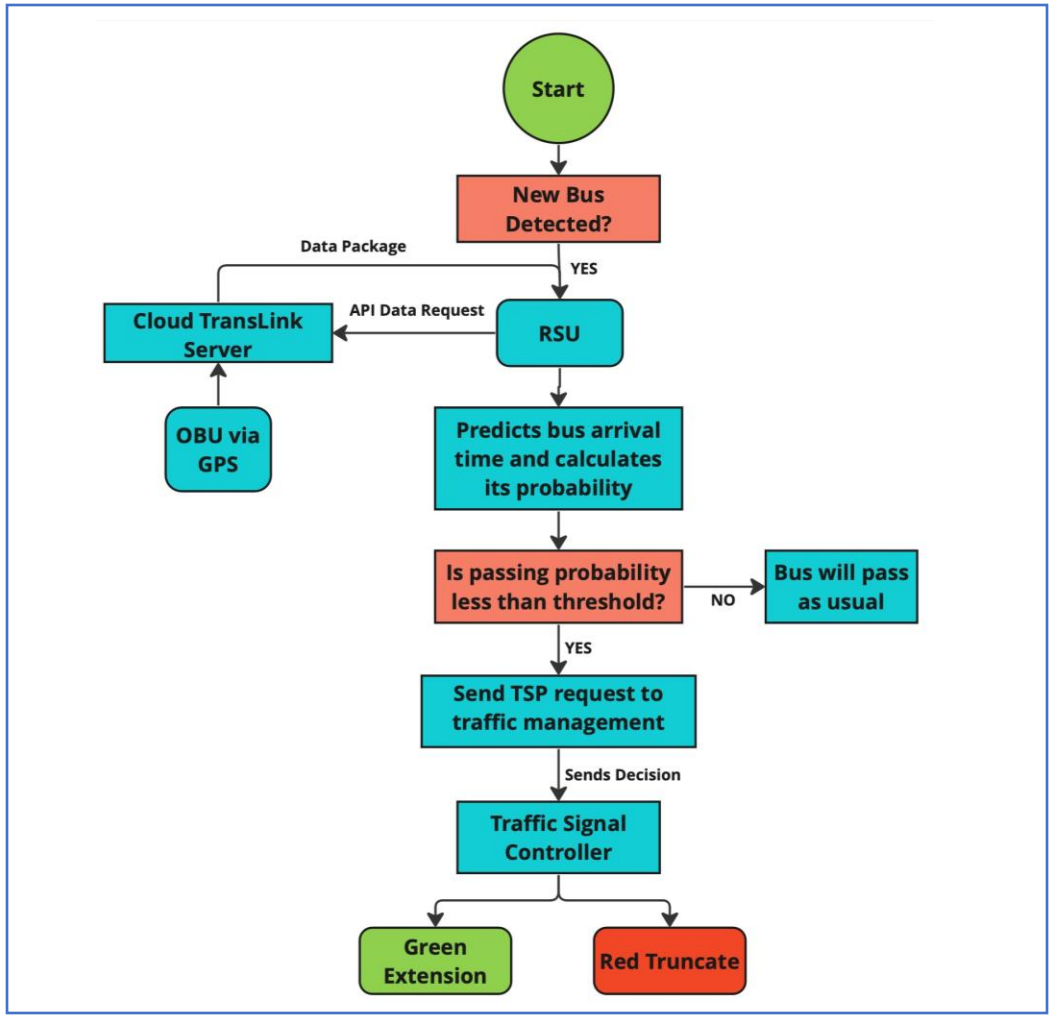
An optimized data flow diagram that aligns with TransLink's data management resources

TransLink API

Real time data package using TransLink's API

TransLink Cloud Server

Scalable and cost effective solution for storing data



What are some incentives for the government to approve a TPS system in their transit management center?

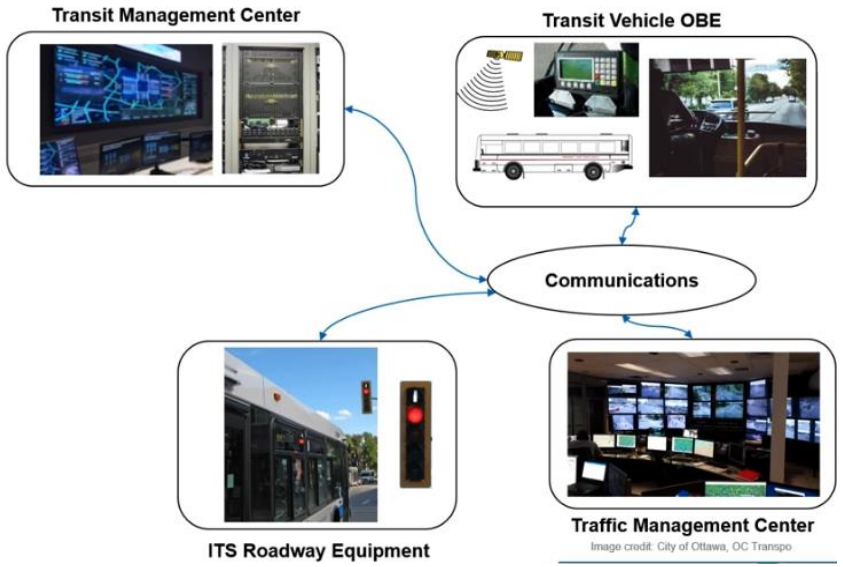
To gain mass approval, TransLink should highlight the key benefits of including the Green Means Go project in Metro Vancouver's transportation planning

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

Key Points for Government Approval

Produces a report on a comprehensive business case for government entities, which considers key factors:

- Ridership
- Expenses and revenues
- Benefits of having traffic signal priority for buses
- Alignment with existing technologies and legacy systems



Deploying TSP project requires a collaborative efforts between TransLink and key stakeholders

Approval to implement technology on city's road infrastructure is required from local, municipal and regional governments in Metro Vancouver

Department of Transportation Canada

Federal department overseeing transportation policies, safety, and standards in Canada

Has developed **Intelligent Transportation System (ITS) infrastructure** to support Canada's road system since 2000

TransLink must refer to Transport Canada's resources for best practices to implement Traffic Signal Priority technologies

Municipalities' Signal Control System

TPS system must be integrated into **the central traffic signal control system** to control traffic lights

Traffic lights are under the control of each municipality in Metro Vancouver

TransLink needs to work with each municipality in Metro Vancouver to implement TPS algorithm into traffic signals in each city

TransLink's Project Team

TransLink's existing technologies on buses can be utilized to effectively integrate the TPS system

TPS system should be developed **in-house** to ensure **data security** for sensitive exchange of communication with government systems

A full project team must be hired and onboarded to develop the system in-house, and deploy it to Metro Vancouver

Key stakeholders that approve TransLink's proposals for transportation projects

Approval to implement technology on city's road infrastructure is required from local, municipal and regional governments in Metro Vancouver

Mayors' Council on Regional Transportation

- Representatives from 21 municipalities & the Tsawwassen First Nation
- **Approves plans proposed by TransLink** (transportation plan, regional funding, borrowing limits)

TransLink Board of Director

- Oversees TransLink's strategic planning, finances, major capital projects and operations.
- **Approves projects**

Regional Transportation Commissioner

- Annually reports to Mayors' Council on TransLink's **performance** against its plans
- Approves plans for annual customer satisfaction surveys

BC Government (Provincial Government)

BRITISH COLUMBIA

TRANSLINK

Regional Transportation Authority in South Coast BC

Metro Vancouver (formerly Greater Vancouver Regional District)

metrovancouver

Change Management Model to Get Municipalities' Buy-In

Approval to implement technology on city's road infrastructure is required from local, municipal and regional governments in Metro Vancouver

Understand the needs of municipalities is a crucial for TransLink to get buy-in for the project

1 Unfreeze	2 Change	3 Refreeze
Convince municipalities of the need to change	**Implement changes to get to the ideal future state**	**Reinforce and stabilize new changes to Metro vancouver's traffic system**
Emphasize current impact on municipalities: • Drive a sense of urgency to encourage change	Assign **responsibilities that match current capabilities** of TransLink and each municipality	Clear **communication and visibility** into TransLink's implementation progress
Communicate public sentiment towards Metro Vancouver's traffic conditions • Survey results from the public	Understand **each municipality's requirements** (technical, security, social,…)	**Ongoing technical support** for municipalities' traffic system
Recognize the need for change	**Support municipalities to implement the changes**	**Work closely together during implementation to maintain ongoing collaboration**

KPIs And Milestones For Each Year Of Implementation

KPIs

2024:
- Percentage completion of system analysis and requirements gathering.
- Number of positions filled in Project Management and Business Development roles.

2025:
- System Integration Approval by BC Ministry of Transportation and Infrastructure.
- Certification or Accreditation from Transportation Canada for V2X transit technology.

2026:
- Completion of training programs for the hired teams.
- Execution of initial security audits or penetration tests for the Intelligence Transit System.

2027:
- **Deployment completion** with 90% operational readiness achieved.
- **95% training satisfaction rate** among trained personnel.

2028:
- Comprehensive **impact assessment.**
- Average **user satisfaction scores** of 4 out of 5.

Milestones

2024:
- Proposal of system concepts to the Board of Directors.
- Finalization of system concept based on feedback from the Board of Directors.

2025:
- Submission and approval of required permits and licenses for the implementation.
- Pilot testing of Transit Signal Priority in select transit corridors.

2026:
- Full-scale deployment of V2X transit technology across designated transit networks.
- Establishment of a fully functional IT infrastructure to support the Intelligence Transit System.

2026:
- Finalization of the technical design phase and the commencement of system development.

2027:
- Regular user engagement initiatives undertaken and user adoption metrics collected.

2028:
- Initiation of the scaling plan with expansion planning milestones achieved.
- Implementation of technology enhancements meeting 80% of identified improvement areas.

Regulations require TransLink to consult with key stakeholders before it can implement a project

The *SCBCTA* Act requires that TransLink consult with the following groups on the investment plan:

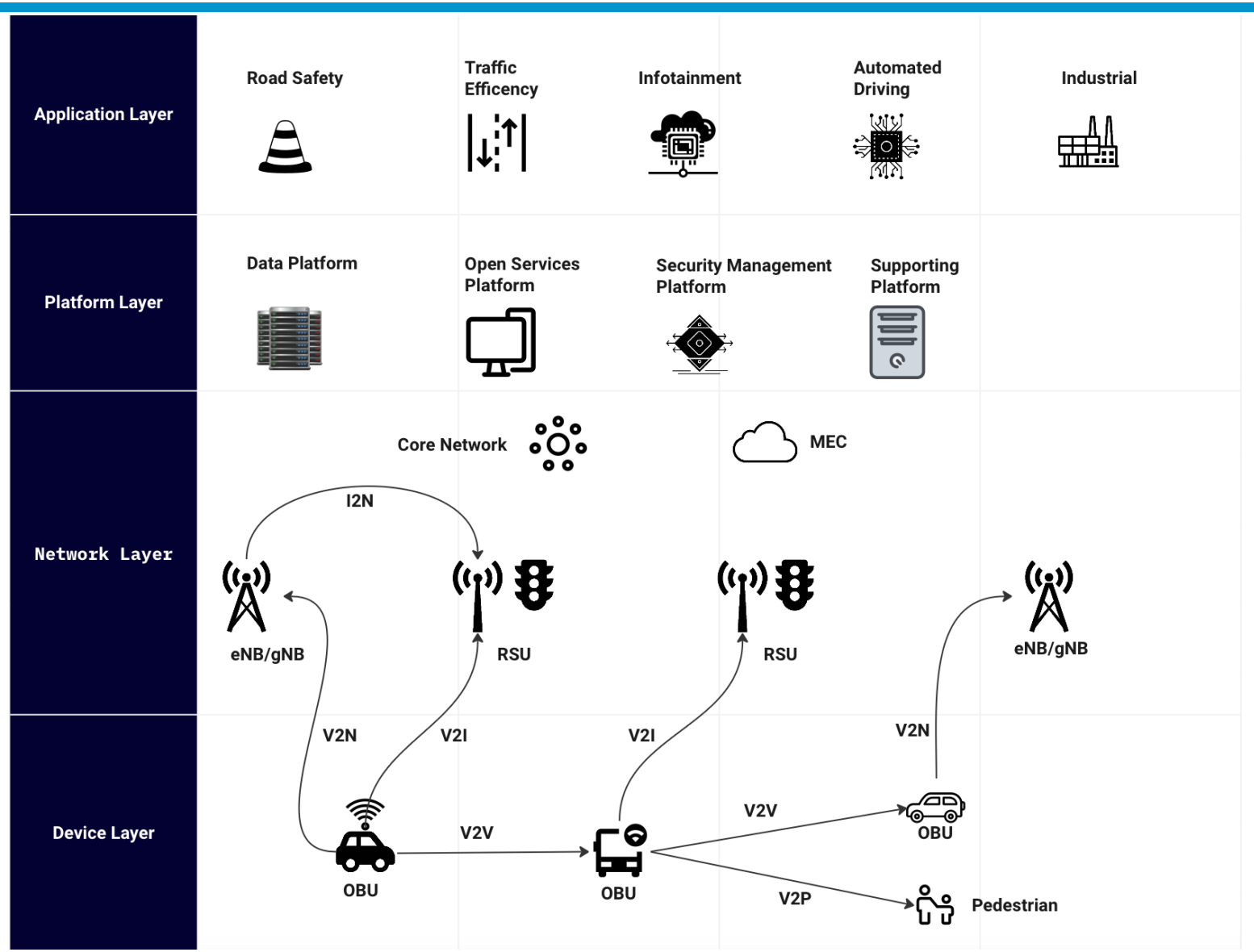
- The public in the transportation service region.
- The Mayors' Council on Regional Transportation.
- Metro Vancouver Regional District.
- Any municipality and other organization that TransLink considers will be affected.

V2X Network Architecture and Standards System

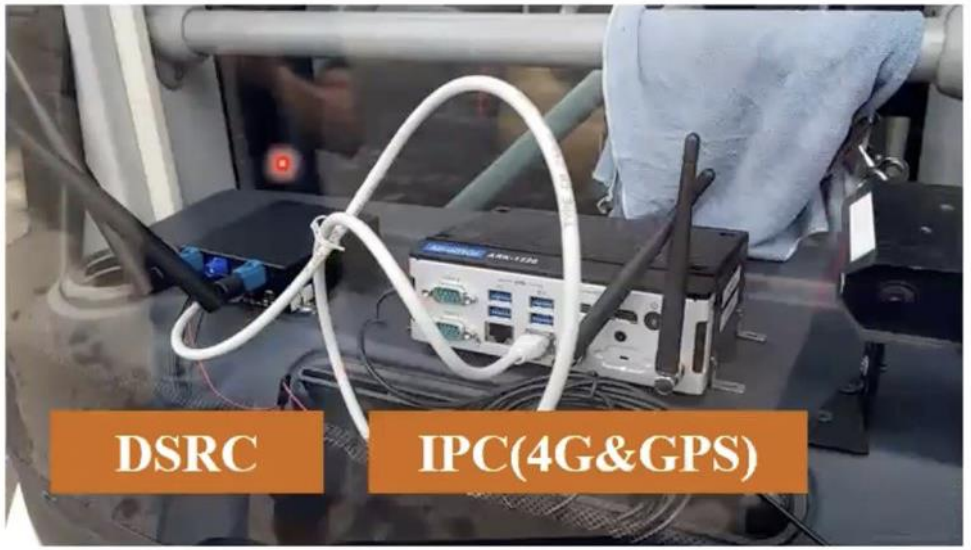
Devices (Device Layer):
- V2X devices like OBUs, RSUs, and mobile phones facilitate wireless communication.
- Enables sharing of vehicle and traffic status info via V2V, V2I, V2P, and other V2X communications.

Pipe (Network Layer):
- V2X and cellular networks use RSUs, 4G/5G stations, and MEC for efficient connections.
- Supports information exchange among vehicles, road infrastructures, and platforms.

Cloud (Platform and Application Layers):
- Platform layer handles data collection, analysis, and open services management.
- Application layer caters to various V2X applications, offering public and industrial services.



Hardware Components



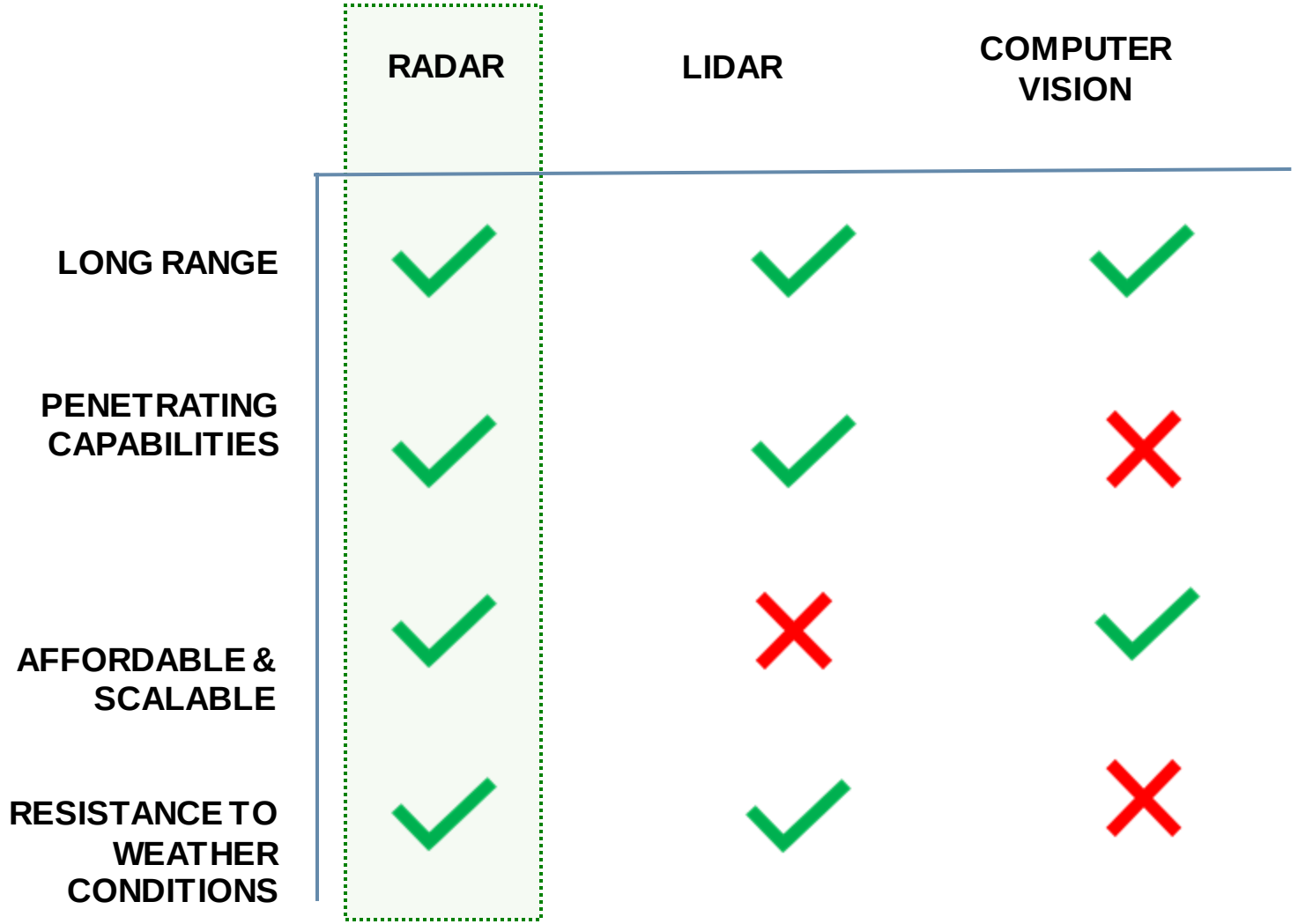
RSU(road-side unit)

The RSU is used to communicate with vehicle and send the control order to traffic controller.

OBU(On-Board Unit)

The OBU contains two parts:
(1) DSRC Module
(2) Industrial Computer

Alternatives of Technology: Radar, Lidar, and Computer Vision



Radar:
- Utilizes radio waves to detect objects.
- Works well in adverse weather conditions.
- Effective in determining object speed and distance.

Lidar:
- Relies on laser light to measure distances.
- Offers high-resolution 3D mapping and detailed object identification.
- Sensitive to weather conditions.

Computer Vision:
- Employs image processing and AI to interpret visual data.
- Enables object recognition and classification.
- Limited by lighting conditions and obstructions.

Experiment Design

SUMO Parameters	Values
Vehicle Type	Electric Bus
Has battery device	True
Length	12
Width	2.55
Height	3.5
Vehicle Mass	11,800
Constant Power Intake	206
Maximum Battery Capacity	200,000

Performance Measure-Intersection
Average delay of main-street vehicle (D-MV)
Average delay of side-street vehicle (D-SV)
Average delay of all vehicles (D-AV)
Average delay of transit vehicle (Bus) (D-TV)

Two type of Traffic V/C ratio (volume to capacity)- 0.9 and 0.5

Movement (veh/hr)	A	B	C	D	E	F
V/C = 0.9	45	543	83	80	1147	131
V/C = 0.5	23	272	42	40	574	66
Movement (veh/hr)	**G**	**H**	**I**	**J**	**K**	**L**
V/C = 0.9	82	530	161	129	814	55
V/C = 0.5	41	265	81	65	407	28

Impact Analysis – Financials

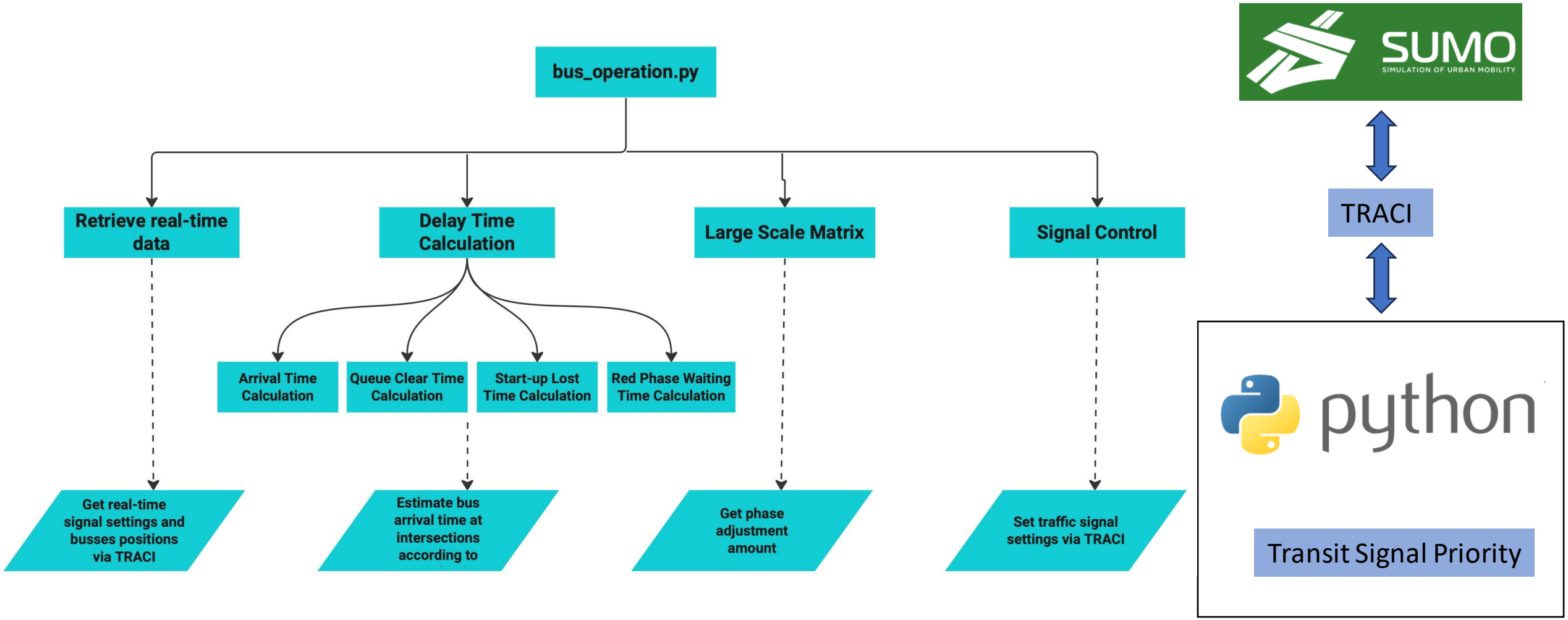
Projected Expenses

Estimated	2024	2025	2026	2027	2028
Infrastructure					
AWS Cloud Development Cost		$10,000.00	$10,000.00	$10,000.00	$10,000.00
Datadog		$3,000.00	$3,000.00	$3,000.00	$3,000.00
EMR		$96,360	$96,360	$96,360	$96,360
Power BI Premium (Per Capacity)		$5,000.00	$5,000.00	$5,000.00	$5,000.00
MongoDB		$840.00	$840.00	$840.00	$840.00
Receiver (Traffic Lamp Upgrade)			$70,000.00		
Totals	**$0.00**	**$18,840.00**	**$88,840.00**	**$18,840.00**	**$18,840.00**
Vehicle Related					
Bus Transmitters			$20,000.00	$54,900.00	
Radar Sensor			$400,000.00	$1,098,000.00	
Totals	**$0.00**	**$0.00**	**$420,000.00**	**$1,152,900.00**	**$0.00**
Labour					
Data Analytics Team	$350,000.00	$350,000.00	$350,000.00	$367,500.00	$367,500.00
Engineers		$425,000.00	$425,000.00	$446,250.00	$446,250.00
Project Management Team	$210,000.00	$210,000.00	$210,000.00	$220,500.00	$220,500.00
Totals	**$560,000.00**	**$985,000.00**	**$985,000.00**	**$1,034,250.00**	**$1,034,250.00**
Contract & Administration					
Administration	$225,000.00	$225,000.00	$225,000.00	$225,000.00	$225,000.00
Training			$2,000.00	$1,000.00	$1,000.00
Contracts & Relevant			$5,000.00		
Totals	**$225,000.00**	**$225,000.00**	**$232,000.00**	**$226,000.00**	**$226,000.00**
Maintenance					
Maintenance Team			$210,000.00	$210,000.00	$210,000.00
Totals	**$0.00**	**$0.00**	**$210,000.00**	**$210,000.00**	**$210,000.00**
Total Expenses	**$785,000.00**	**$1,228,840.00**	**$1,935,840.00**	**$2,641,990.00**	**$1,489,090.00**

Projected Savings

Road Delay Cost			$20,000,000.00	$28,000,000.00	$40,000,000.00
Total Saving	**$0.00**	**$0.00**	**$20,000,000.00**	**$28,000,000.00**	**$40,000,000.00**
Total Saving/Loss	**($785,000.00)**	**($1,228,840.00)**	**$18,064,160.00**	**$25,358,010.00**	**$38,510,910.00**
$63,923,966.92	($785,000.00)	($1,148,448.60)	$15,777,936.94	**$20,699,689.73**	**$29,379,788.85**

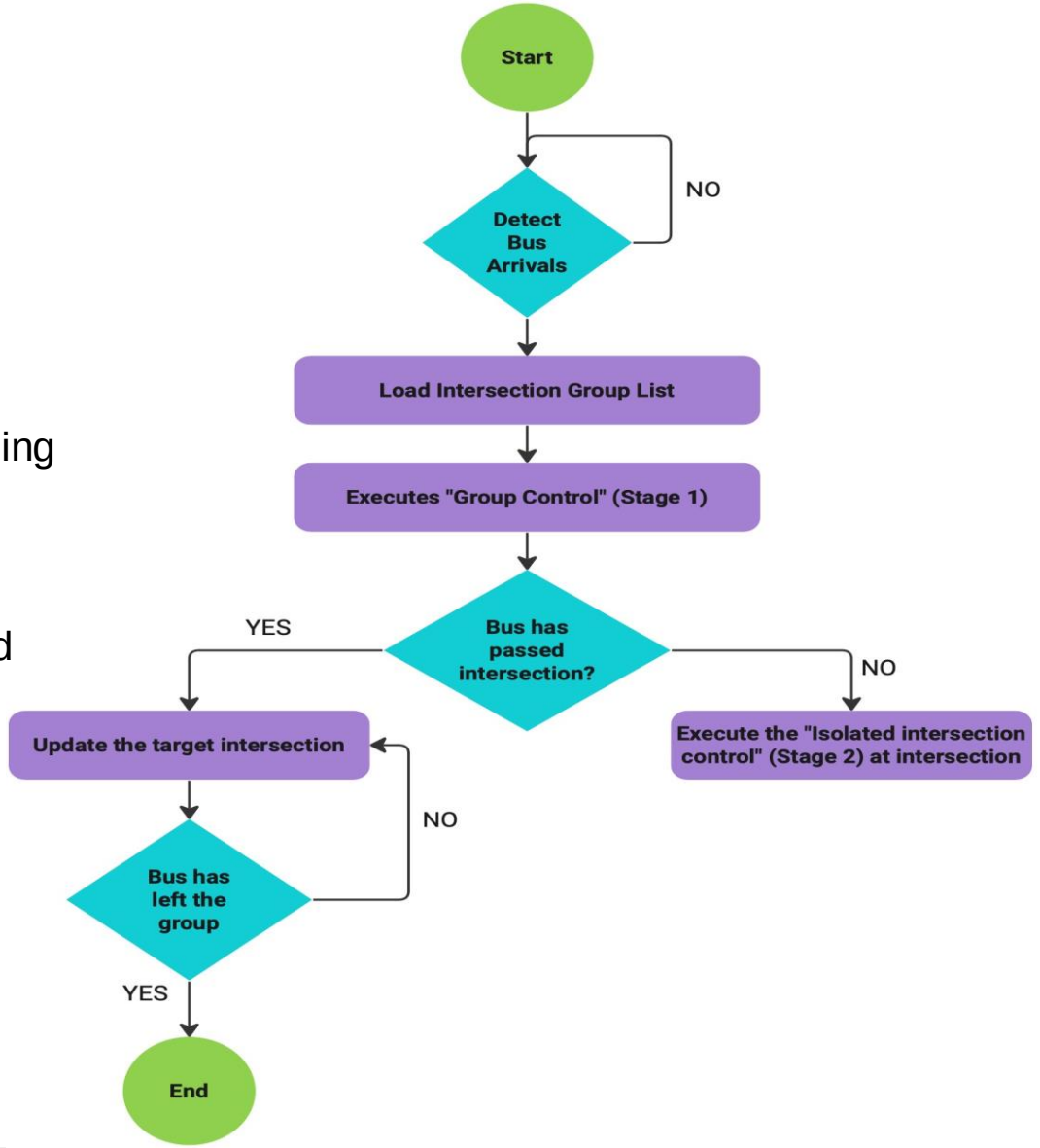
Simulation Framework Using SUMO (Simulation Of Urban Mobility)



TSP Simulation Using SUMO (Simulation Of Urban Mobility)

In the simulation, the TSP strategy operates as follows:

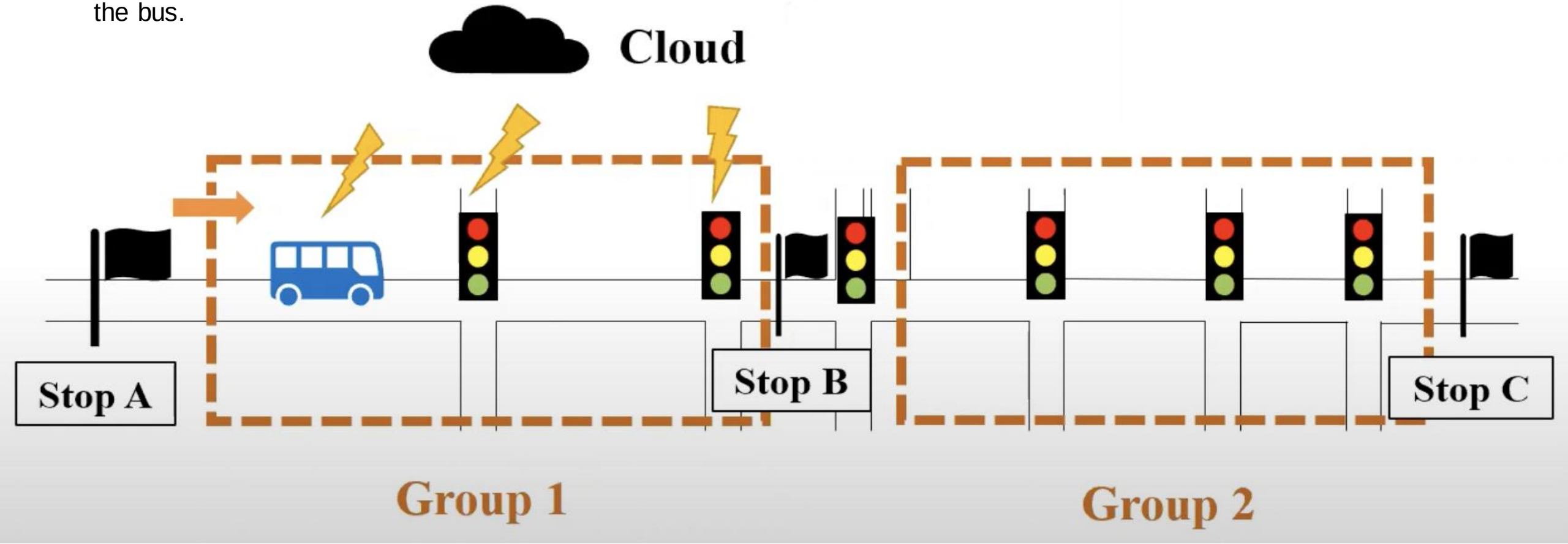
- Continuously monitor the bus's position at each time step, assessing its proximity to trigger points.
- Compile a list of intersections within the designated group and implement "Group Control."
- Sequentially apply isolated-intersection control within the specified group.



Explanation of Simulation's Decision Factors

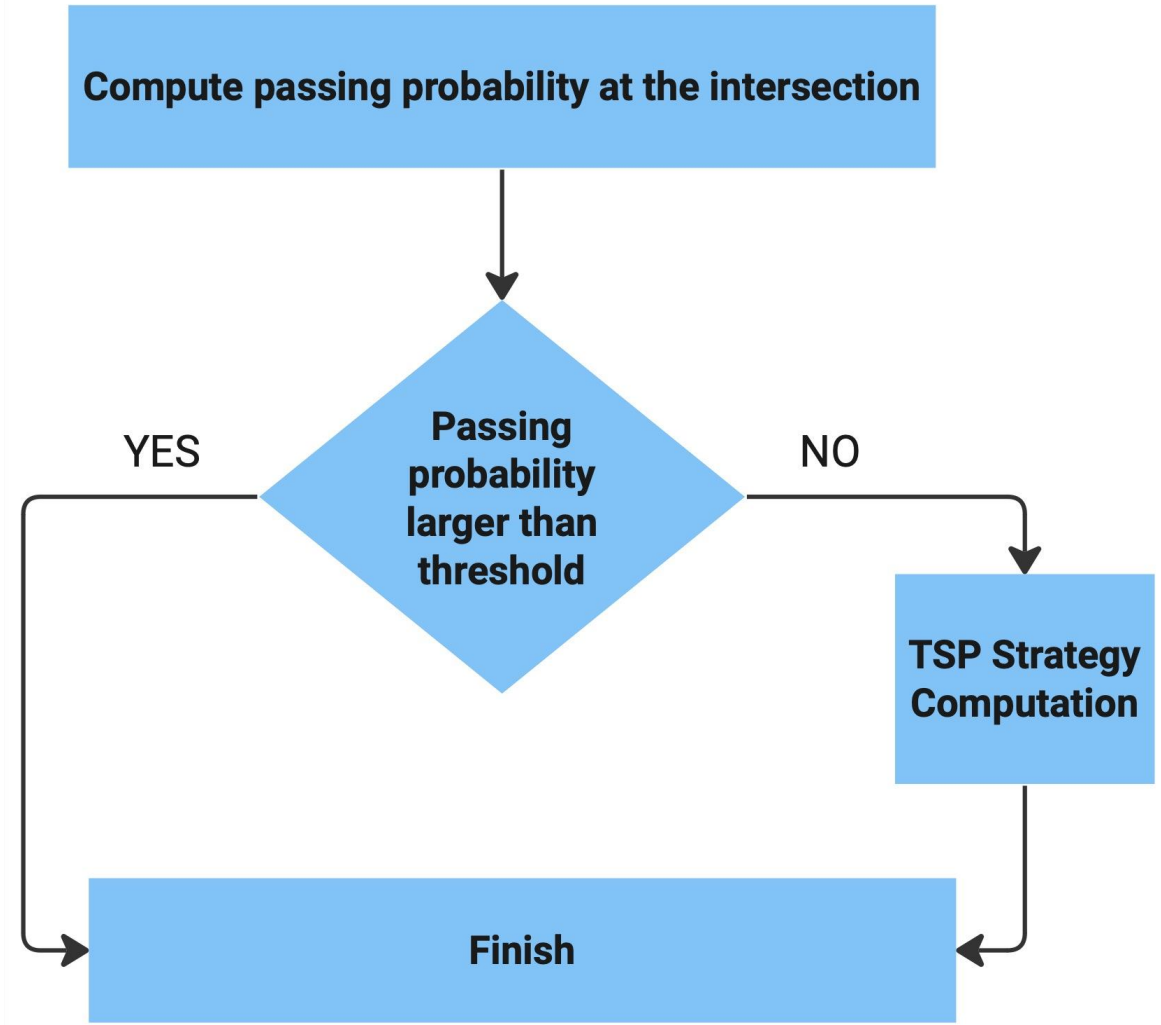
STAGE 1: INTERSECTION GROUP CONTROL

- Definition of "Intersection Group": A collective term referring to the intersections situated between two consecutive bus stops.
- Objective of Intersection Group Control: To establish a synchronized **green wave** that optimally supports the trajectory of the bus.



Explanation of Simulation's Decision Factors

STAGE 2: ISOLATED GROUP CONTROL

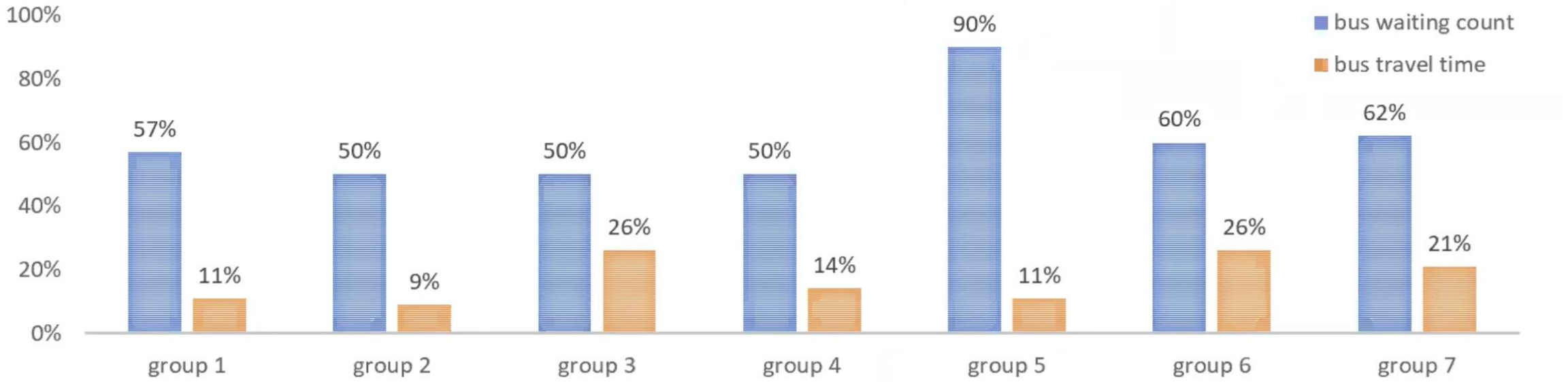


In this stage, signal control occurs on a per-second basis. To enhance computational efficiency, we leverage a comprehensive pre-computed matrix.

The RSU (Roadside Unit) executes the control strategy based on the matrix, utilizing indices such as distance, current phase, and remaining time.

Details of Simulation Results

Result of Simulation: The TSP system grants buses' signal priority requests and effectively reduces bus delays as planned



- **Fixed Time Control**
- **Mixed Time Control** which constitutes Stage 1 (Intersection Group Control) and Stage 2 (Isolated Group Control)
- **21 intersections were grouped into 7 intersection group**.

Results of each intersection group

Group 1	Waiting count	Travel time
Fixed	4.67	196.00
Mixed	2.00	175.17
	-57%	-11%

Group 3	Waiting count	Travel time
Fixed	0.67	58.83
Mixed	0.33	43.67
	-50%	-26%

Group 5	Waiting count	Travel time
Fixed	0.50	47.60
Mixed	0.05	42.21
	-90%	-11%

Group 7	Waiting count	Travel time
Fixed	2.17	179.17
Mixed	0.83	142.21
	-62%	-21%

Group 2	Waiting count	Travel time
Fixed	1.33	105.67
Mixed	0.67	95.67
	-50%	-9%

Group 4	Waiting count	Travel time
Fixed	0.67	76.17
Mixed	0.34	65.43
	-50%	-14%

Group 6	Waiting count	Travel time
Fixed	0.83	87.83
Mixed	0.33	65.43
	-60%	-26%

	Waiting count	Travel time
Avg	-60%	-16%

Current Limitations And Future Work

LIMITATIONS

Real-time data can only be collected from **buses**

System is currently only used to **prevent bus delays**

Infrastructure Dependency:
- Effectiveness depends on the availability and implementation of compatible infrastructure.
- This may not be available in all municipalities.

Continuous Monitoring:
- Continuous maintenance of technical hardware is required.

FUTURE WORKS

Technologies behind TSP system can be expanded to **collect data from other vehicles** and **introduce more use cases of Smart Traffic System**

System can be **extended** to other **TransLink services.**

Example:
- Vehicles can be given speed warnings if they emit real-time data of overspeeding.
- TSP capabilities extended to pedestrians, cyclists, other modes of mobility.

Source: Deep reinforcement learning for transit signal priority in a connected environment. Transportation Research Part C: Emerging Technologies, 142,

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