Hybrid Scheduling for Public Transport with Runtime Variability

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Foundations and Study Overview

Why This Matters

- Urban bus networks worldwide face increasing runtime variability due to congestion, traffic signals, weather, and special events.

Auckland is no exception, our frequent-network corridors show strong AM and PM peak volatility.

Traditional static schedules, which rely mainly on historical averages, often fail under these conditions.

The consequences include late arrivals, bus bunching, overcrowding, and a poor customer experience.

- This study asks a simple question:
  Can runtime be treated as a dynamic variable—updated continuously—rather than a fixed number?

Foundations and Study Overview

Why Hybrid Scheduling for Auckland's Frequent Network

- **Challenges of Static Timetables**
- Static timetables struggle with variability caused by commuting patterns, weather, and congestion leading to delays and uneven service.
- **Hybrid Scheduling Approach**
- Combines robust timetable design with adaptive real-time control to dynamically adjust bus operations and improve reliability.
- **Data-Driven Runtime Modeling**
- Uses multivariate regression and Kalman filtering with live AVL and traffic signals to predict and adjust runtimes.
- **Benefits and Operational Realities**
- Improves on-time performance, reduces driver stress, driver scheduling, and customer information constraints.

Research Goal

Evaluate whether a hybrid scheduling approach, combining robust timetable design and real-time runtime estimation, can materially improve:

- Late arrivals
- On-time performance (OTP)
- Operational efficiency
- Network resilience

Data Sources

The analysis draws on multiple datasets:

- **AVL (Automatic Vehicle Location)** traces for realised runtimes
- **GTFS** static schedules
- **Historical traffic patterns** such as speed indexes
- **Contextual factors:** day-of-week, holidays, weather, and school term indicators

The combination gives both predictive power and contextual nuance.

Method 1: Historical Runtime Modelling

First, we built a multivariate regression model to estimate link-level runtime:

- Time-of-day
- Day-of-week
- Holidays
- Weather
- School term status
- Local speed index
- Fixed effects for route geometry

This produces a **baseline runtime profile** for each corridor and its variance structure.
It is the "robust" foundation of the hybrid model.

Method 2: Online Update via Kalman Filter

Next, we incorporate real-time AVL observations using a **state-space model** with a **Kalman filter**.

The filter continuously blends:

- The historical prediction (prior)
- The latest observed runtime (measurement)

This yields fast, stable short-horizon forecasts, perfect for real-time holding, buffer reallocation, and proactive control.

Hybrid Scheduling Framework

The hybrid framework works in two layers:

1. Ex-ante robust timetable design

- Minimises total slack (reducing the extra or unused time built into a schedule)
- Concentrates buffer where variability is highest
- Ensures vehicle and driver feasibility

2. In-operation adaptive control

- Conditional holding
- Small within-trip slack adjustments
- Headway-based dispatch informed by real-time forecasts

This dual structure is what generates the reliability gains.

Results: Reliability

Key Findings:

- **Late arrivals reduced by 23.4%**
  $p < 0.01$

- **On-time performance improved by 18.7%**

These are large and statistically robust gains—even on high-variance peak corridors.

Chart 1 — Late Arrivals Comparison

23.4% reduction in late arrivals

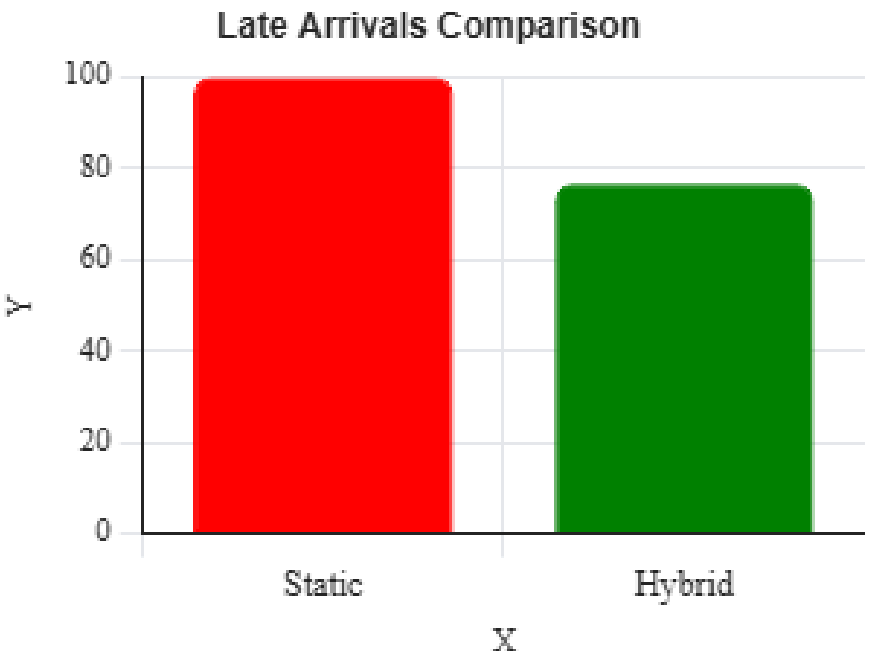
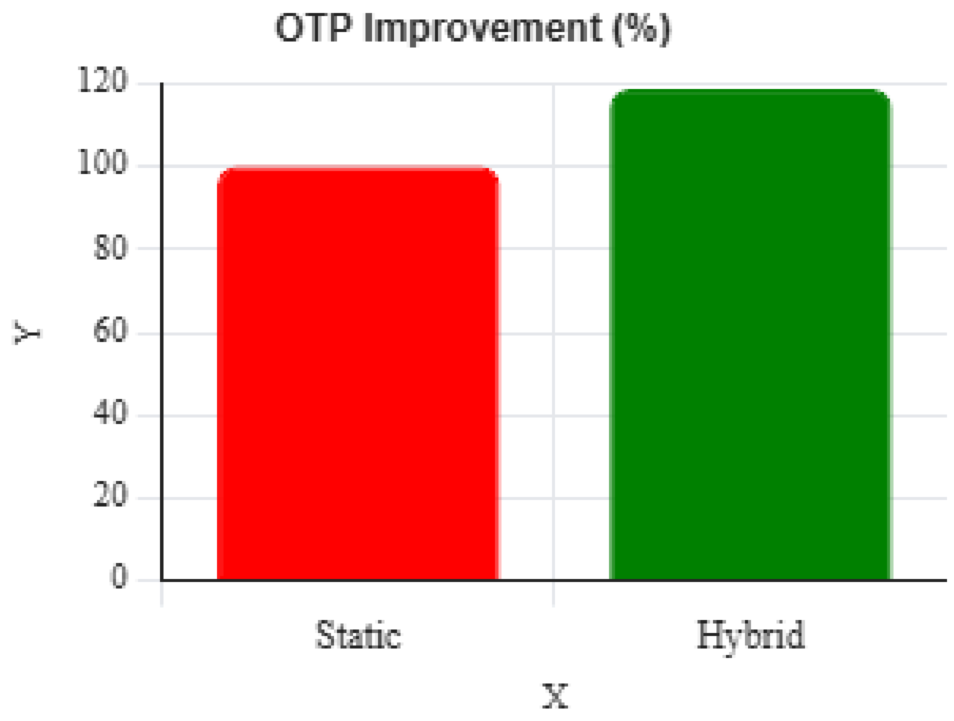


Chart 2 — OTP Improvement

18.7% improvement in on-time performance.



Results: Operational Stability

By concentrating buffer at high-variance segments and applying conditional holding, the hybrid method:

- Stabilises headways
- Reduces bunching
- Lessens the need for manual interventions by controllers
- Lowers dead mileage

This leads to smoother, more predictable service delivery.

Why It Works

The value comes from balancing two strengths:

- **Historical data** → excellent for predicting average conditions
- **Real-time data** → critical for responding to today's traffic

Together, they form a resilient approach that absorbs variability instead of amplifying it.

Conclusion

To conclude:

- Treating runtime as **dynamic** yields large gains in both reliability and efficiency.
- The hybrid robust–adaptive framework reduces late arrivals, improves OTP, and enhances resilience.
- This is a practical, evidence-backed pathway for improving frequent bus networks in Auckland.

Future Work

Next steps include:

- Integrating weather and event prediction models
- Scaling the framework across more corridors
- Testing deep-learning runtime models
- Evaluating impacts on passenger waiting times and occupancy

Thank you. I am happy to take any questions

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