Dynamic Coupling and Scheduling of High-Speed Rail Carriages: Toward AI-Guided, Continuous Passenger Transport

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1 Abstract

High-speed and urban rail systems frequently face trade-offs between scheduling efficiency and passenger accessibility. This paper proposes a novel transportation framework based on dynamically coupling and decoupling train carriages in motion, enabling selected carriages to serve stations while the main train body continues at cruising speed. This system architecture, referred to as the *Snowpiercer Model*, aims to emulate continuous-flow transport by decoupling the traditional link between full-train halts and passenger boarding.

Using the Singapore Mass Rapid Transit (MRT) and the Tōkaidō Shinkansen as case studies, we model potential implementations and estimate theoretical travel time reductions of up to 53%—achieved without requiring new track infrastructure. The model is particularly effective in dense transit networks, where frequent stops create operational bottlenecks. We also examine the feasibility of dynamic station capacity and carriage allocation strategies, along with limitations related to engineering constraints, accessibility, and system integration.

Finally, we outline how artificial intelligence could enable real-time scheduling, routing, and passenger flow optimization, positioning the Snowpiercer model as a foundation for intelligent modular rail systems.

2 Introduction

This paper introduces a novel paradigm in high-speed passenger rail: the dynamic coupling and decoupling of train carriages in motion. To establish clarity, we begin by defining two core terms used throughout this work: **carriages** and **trains**.

A **carriage** refers to any self-contained unit of rolling stock—such as wagons or Electric Multiple Units (EMUs)—that can be physically coupled with others to permit continuous passenger movement via an open gangway[1].

A **train**, in contrast, is more challenging to define due to its impermanent composition. In our framework, a train represents a transient formation of carriages physically coupled between any two stations—a modular entity subject to continual reconfiguration. This is conceptually analogous to the Ship of Theseus[2], where the identity of the whole persists despite ongoing replacement of its components.

The focus of this paper is not on resolving the mechanical or control-system challenges required to realize such dynamically modular carriages. Rather, our aim is to establish the theoretical and operational framework underpinning what we term the *Snowpiercer Model*, and in particular its extension to so-called *perpetual phantom trains*—a continuous flow of modular carriages that enables seamless passenger transport without full-stop schedules.

To develop this concept, the paper is structured as follows:

- Chapter 3 introduces the core design principles behind the proposed model.
- Chapter 4 details the *Snowpiercer* system architecture and operational logic.
- Chapter 5 presents the mathematical methods used in simulation and scheduling.
- Chapter 6 explores a case study applied to Singapore's MRT.

- Chapter 7 considers a high-speed rail implementation via the *Tōkaidō Shinkansen*.
- Chapter 8 explores the potential of AI integration for scheduling and control.
- Chapter 9 concludes with implications, limitations, and areas for future work.

3 Preliminary Concept

3.1 Inception

This proposal originated from a simple but underexplored observation: current train operations require an entire train to stop at each station, even though only a fraction of passengers may be boarding or alighting. This creates inefficiencies in both scheduling and energy usage. Motivated by this mismatch between infrastructure usage and passenger flow, we sought a system that could selectively decouple carriages to serve stations without halting the full train.

3.2 Dynamic Coupling and Decoupling Carriages

To realize this idea, a fundamentally new class of rail vehicles is required —capable of safe and efficient coupling and decoupling at operational speeds.

A detailed taxonomy of such capabilities is presented by Nold and Corman[1], who define multiple categories of dynamic coupling in their paper, *Dynamic train unit coupling and decoupling at cruising speed: Systematic classification, operational potentials, and research agenda.* According to their framework, the proposed Snowpiercer system requires carriages classified as **Unit Coupling in Operation (UCO) 4.3**: vehicles that can perform automatic coupling and decoupling at cruising speeds and allow for safe passenger transfer between vehicles while in motion.

Unless otherwise stated, all subsequent discussion assumes carriages with full UCO 4.3 capability.

3.3 Station Bypass via Side Track

To enable selective stopping without requiring the entire train to decelerate, a dedicated side track is introduced. This track allows a subset of carriages—either leading or trailing—to decouple from the main train and pull into the station independently, while the remaining carriages bypass the station at cruising speed. The decoupling procedures are illustrated in Figures 1 and 2.

After completing the boarding and alighting process, the detached carriages must rejoin the main train before the next station. As with decoupling, this reattachment can only occur at either the front or rear of the non-stopping carriages. The corresponding coupling sequences are shown in Figures 3 and 4.

Detailed timing, acceleration requirements, and merge logistics are discussed in subsequent sections.

Some notes before studying Figures 1 through 4:

- Each figure is divided into four horizontal segments, with the topmost configuration occurring first.
- Trains and carriages always travel from left to right.
- A carriage is represented by a purple rectangle, outlined in black.
- The red/green semicircular lights at the front and back of carriages indicate if two consecutive carriages are physically coupled, with green indicating coupled, red otherwise. Once coupled, passengers can transfer within those carriages.
- It is assumed that along each side track is a train station.
- The reader is **strongly encouraged** to view the accompanying animated media alongside Figures 1 through 4. This media can be found on the author's personal site here[3].

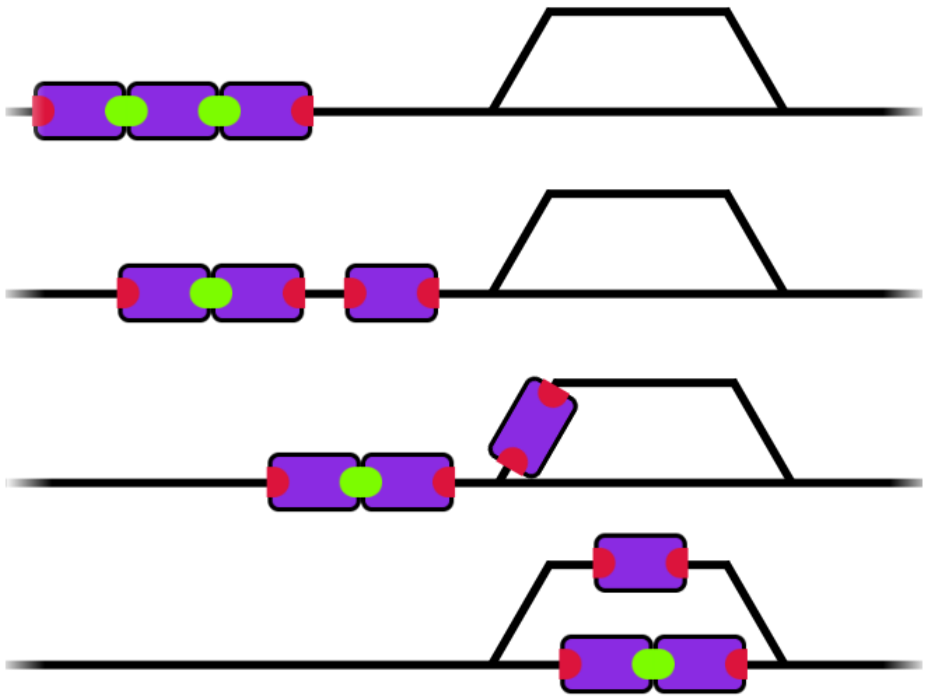

Figure 1 - Leading carriage decoupling sequence

The full description of Figure 1 is as follows, with each point describing each configuration from top to bottom:

1. Three coupled carriages are travelling at cruising speed towards the right.
2. The leading carriage dynamically decouples and accelerates.
3. The leading carriage accelerated towards the switch and diverted onto the side track, while the trailing two carriages continue on the main track.
4. The leading carriage was slated for arrival at this station and has stopped along the side track. The switch reverted immediately after diverting the leading carriage, allowing the trailing carriages to continue at cruising speed along the main track.

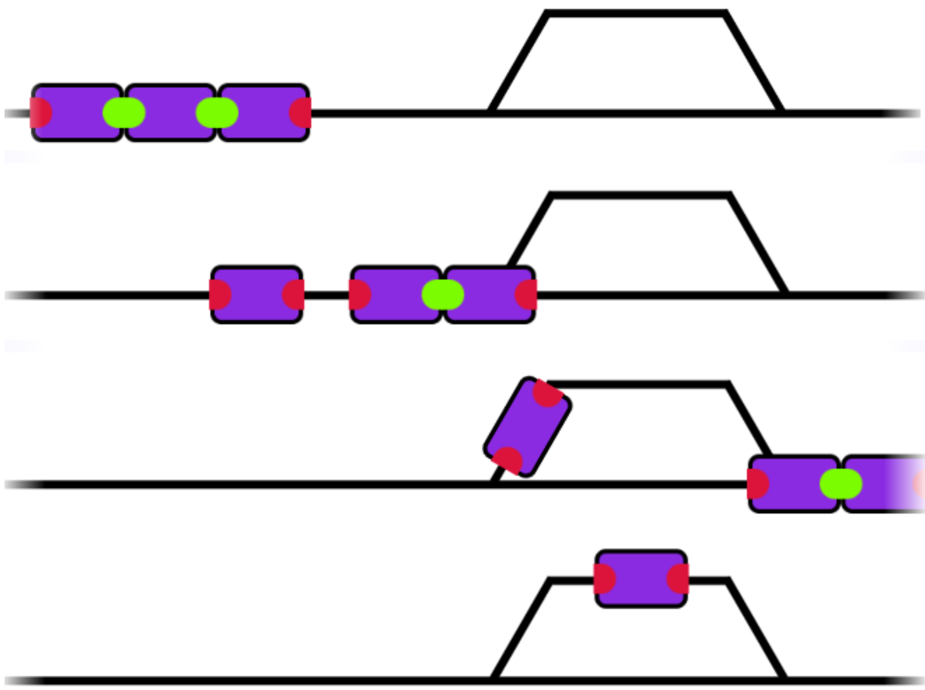

Figure 2 - Trailing carriage decoupling sequence

1. Three coupled carriages are travelling at cruising speed towards the right.

2. The trailing carriage dynamically decouples and decelerates. The leading two carriages continue at cruising speed past the switch and along the main track.

3. After the leading carriages pass the switch, the trailing carriage is diverted onto the side track.

4. The leading carriages have travelled off-screen along the main track, while the trailing carriage has decelerated to a stop along the side track.

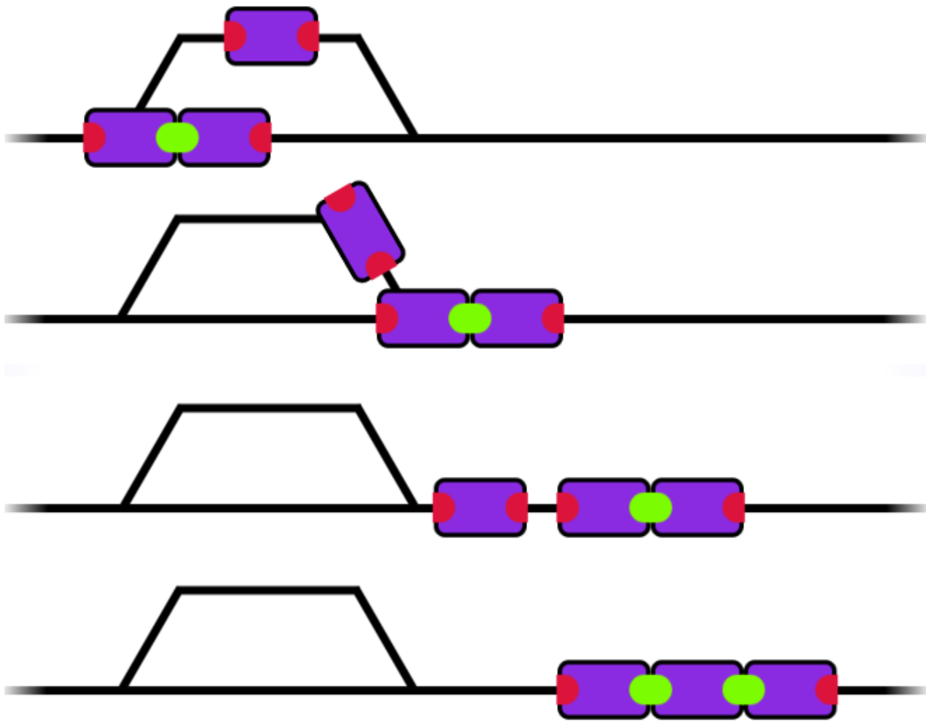

Figure 3 - Trailing carriage coupling sequence

1. Along the side track is a stationary carriage while two coupled carriages are travelling along the main track at cruising speed.
2. After the coupled carriages pass the side track, the solitary carriage accelerate to join the main track. This makes the solitary carriage also the trailing carriage.
3. After joining the track, the trailing carriage accelerates towards the leading carriages.
4. The trailing carriage dynamically couples with the leading carriages, after which all three carriages travel as a singular train along the main track.

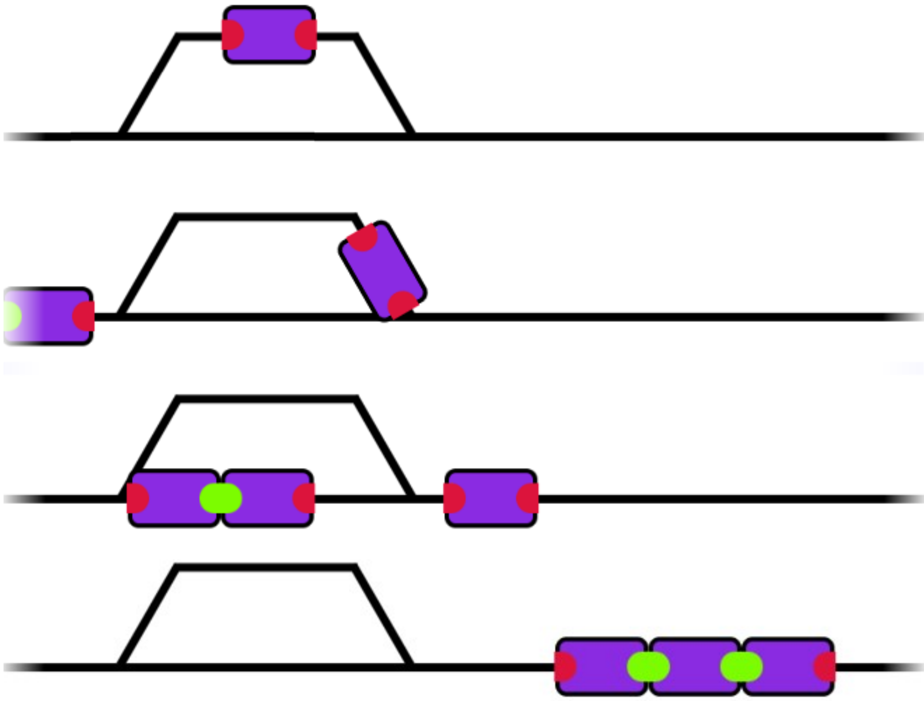

Figure 4 - Leading carriage coupling sequence

1. Along the side track is a stationary carriage.
2. The first of two coupled carriages is visible on the left of the main track. These coupled carriages are travelling at cruising speed. The solitary carriage accelerates along the side track, preparing to join the main track. This makes the solitary carriage also the leading carriage.
3. After joining the track, the leading carriage decelerates to allow the trailing carriages to catch up.
4. The leading carriage dynamically couples with the trailing carriages, after which all three carriages travel as a singular train along the main track.

4 *Snowpiercer*

4.1 Single Track Operation

A key insight emerging from the sequences illustrated in Figures 1 through 4 is that the deposition and collection of carriages at stations can, under certain conditions, be accomplished without the need for a side track—while allowing the main train body to maintain cruising speed.

This is made possible through specific combinations of coupling and decoupling strategies, namely those shown in Figures 2 and 4. In these sequences, a trailing carriage is decoupled (Figure 2) and a leading carriage is subsequently coupled (Figure 4). Unlike the operations depicted in Figures 1 and 3, which require a side track to enable overtaking maneuvers, these strategies avoid any such overtaking. As a result, the system can be operated entirely on a single track, as illustrated in Figure 5.

This finding significantly lowers infrastructure requirements and broadens the feasibility of implementation, particularly in densely built or cost-sensitive urban environments.

Some notes before studying Figure 5:

- Instead of horizontal segments, Figure 5 is divided into four **vertical** segments, with the **leftmost** configuration occurring first.
- Carriages travel from South to North.
- The carriages involved are identified as *A*, *B*, and *C*.
- The rightmost red line and label *NS 13 - Yishun* serves to demarcate the station location. Context – *Yishun* is along the North-South Line served by Singapore's MRT network, and this station is the author's favourite.
- The reader is once again **strongly encouraged** to view the accompanying animated media alongside Figure 5 here[4].

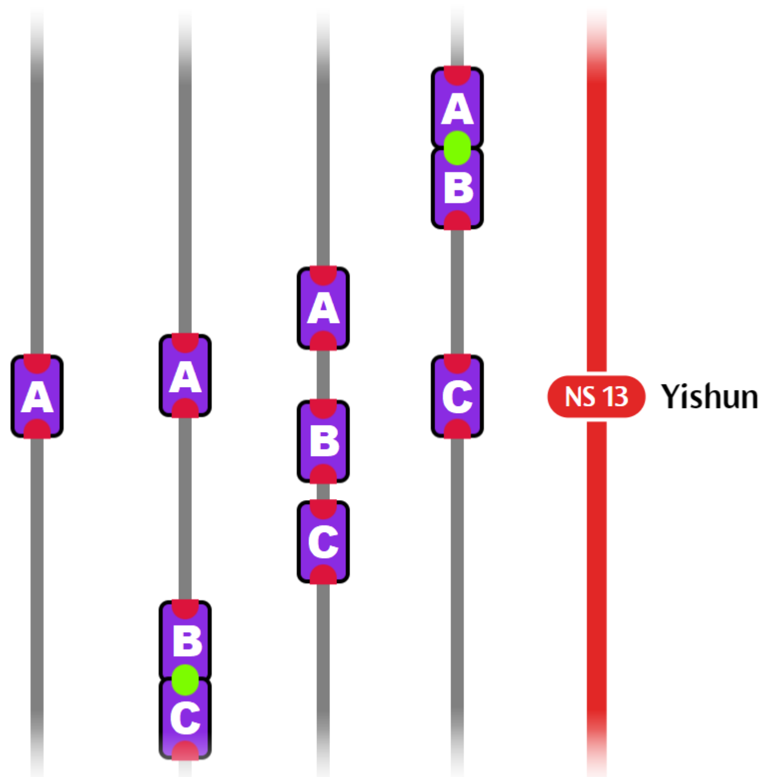

Figure 5 - Schematic of *Snowpiercer*'s novel single track operation

1. A is stopped at *Yishun* station.
2. A pair of coupled carriages B and C approach from the South at cruising speed, and A can be seen accelerating slightly.
3. A accelerates further, as its speed needs to match B eventually. B continues at cruising speed. C has just dynamically decoupled from B, and is decelerating in preparation to stop at the station.
4. A accelerated precisely such that B, which is travelling at a constant cruising speed, could just "catch" A. A and B have dynamically coupled and C has decelerated to a complete stop at *Yishun* station.

This process can be easily looped as C simply takes over the role of A in the next cycle.

This base-case illustration of *Snowpiercer*'s single track operation had the parameters:

- Station capacity – **1 carriage**
- Phantom train length – **2 carriages**

These two parameters are readily apparent as illustrated by solitary carriages A and C having stopped at the station, while also coupled carriages [B, C] having arrived at station, and [A, B] having departed the station. In fact, these two parameters are the absolute minimum that can allow *Snowpiercer* to function.

While preserving train length, the phenomenon of having different arriving and departing carriages is what constitutes the **phantom** train effect of *Snowpiercer*.

Another defining feature of *Snowpiercer* is the guarantee of at least one carriage passing through a station without ever decelerating. In the case of Figure 5, this would be carriage B. The guarantee of this passing through carriage allows passengers to avoid stopping at all irrelevant stations en route to their destination. This feature is responsible for the **perpetual** train as claimed in this paper's title.

Being deployable without the need for side tracks, *Snowpiercer* perpetual phantom trains is likely viable in many existing railway services, pending the development of the necessary UCO 4.3 carriages.

4.2 Dynamic Station Capacity

In addition to single track operation, it is also possible for stations along the same line to host different numbers of carriages.

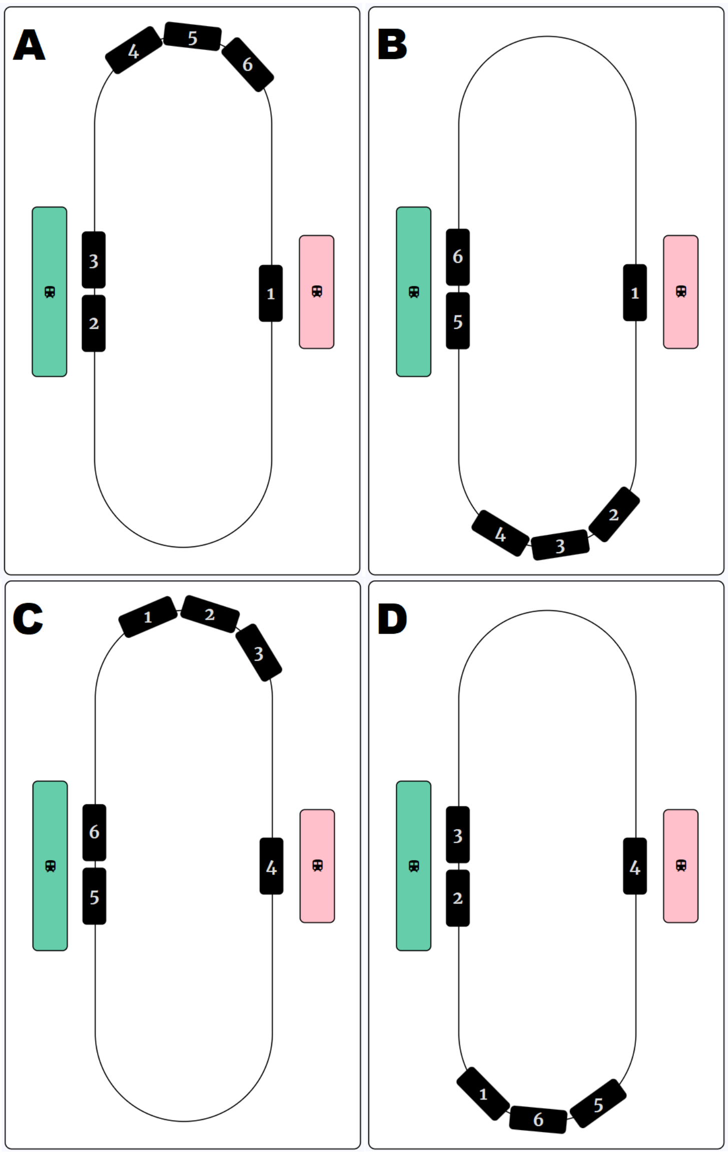

Figure 6 - Dynamic station capacity [animation][5]

Figure 6 is an overhead illustration of a hypothetical *Snowpiercer* railway service with two stations of varying carriage capacities (Green station with 2 carriages, and Red station with 1 carriage). The figure is a collage of four configurations intended to be read alphabetically as indicated by their panel labels on the top left (*A, B, C, D*). In each panel is a configuration of the carriages while in service, and they illustrate the practicality and cyclical nature of dynamic station capacity in operation.

To fully appreciate the intricacy of *Snowpiercer* in action, the reader is once again **strongly encouraged** to view the accompanying animated media alongside Figure 6 here[5].

The detailed explanations of each panel are as follows:

- Notes – All carriages are travelling counter-clockwise. In the absence of coupling/decoupling indicators, the coupling statuses of carriages are inferred.
- Panel A – Carriage 1 is stopped at Red station, while the coupled Carriages [2, 3] are stopped at Green station. The train comprising Carriages [4, 5, 6] is travelling towards the Green station.
- Panel B – The train has picked up Carriages [2, 3] while simultaneously dropping off Carriages [5, 6] at Green station. Carriage 4 passed Green station without decelerating. The train now comprises Carriages [2, 3, 4] and is now travelling towards Red station.
- Panel C – The train has picked up Carriage 1 while simultaneously dropping off Carriage 4 at Red station. Carriages [2, 3] passed Red station without decelerating. The train now comprises Carriages [1, 2, 3] and is now travelling towards Green station.
- Panel D – The train has picked up Carriages [5, 6] while simultaneously dropping off Carriages [2, 3] at Green station. Carriage 1 passed Green station without decelerating. The train now comprises Carriages [5, 6, 1] and is now travelling towards Red station.
- Panel A (again) – The train has picked up Carriage 4 while simultaneously dropping off Carriage 1 at Red station. Carriages [5, 6] passed Red station without decelerating. The train now comprises Carriages [1, 2, 3] and is now travelling towards Green station.

5 Mathematical Methods

Having established the working principle in the previous two chapters, we now formalise mathematical methods with which we will determine the operational effectiveness of *Snowpiercer*.

5.1 Travel Time

Given two arbitrary consecutive stations, the travel time in seconds (t) between them can be expressed with the following three parameters:

- a – acceleration in ms^{-2}
- v – cruising speed in ms^{-1}
- d – track distance in m

Assuming (1) constant acceleration and deceleration, (2) constant cruising speed, and (3) the track being long enough such that cruising speed is always attained, the speed versus time graph is depicted as such:

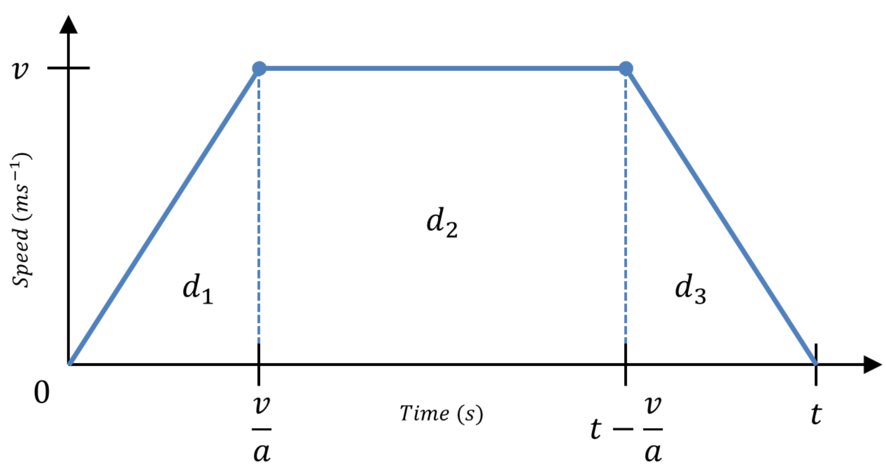

Figure 7 - Speed vs Time graph between two consecutive stations

We derive from Figure 7 the track distance d as the total area under the curve:

$$d = d_1 + d_2 + d_3 \tag{1}$$

Expanding its constituents,

$$\begin{aligned} d_1 &= \frac{1}{2} \cdot \frac{v}{a} \cdot v \\ &= \frac{v^2}{2a} \end{aligned} \tag{2}$$

$$d_2 = \left(t - \frac{2v}{a}\right) \cdot v \tag{3}$$

$$d_3 = d_1 \tag{4}$$

Simplifying d,

$$\begin{aligned} d &= \frac{v^2}{2a} + \left(t - \frac{2v}{a}\right) \cdot v + \frac{v^2}{2a} \\ &= \frac{v^2}{a} + \left(t - \frac{2v}{a}\right) \cdot v \\ &= \left(\frac{v}{a} + t - \frac{2v}{a}\right) \cdot v \\ &= \left(t - \frac{v}{a}\right) \cdot v \end{aligned} \tag{5}$$

Making t the subject,

$$t = \frac{d}{v} + \frac{v}{a} \tag{6}$$

Having derived the expression for the travel time between two consecutive stations, we now tackle the slightly more complex expression for three or more stations. In the following examples, Stations A, B, C, and D form four consecutive stations along the same line; t_{AB} represents the travel time from A to B.

Figure 8 - Arbitrary consecutive stations A, B, C, and D

To meaningfully calculate t_{AC} or t_{AD}, we need to introduce a new temporal variable, though in this paper it will be a constant in the interest of simplicity. This constant is the duration in seconds which the train stops at a station, represented by S.

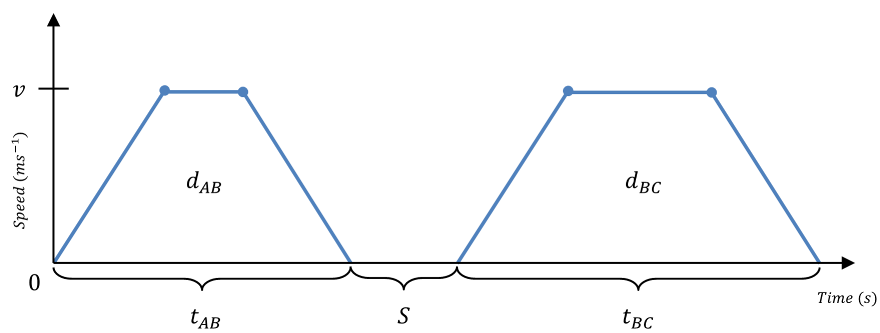

Figure 9 - Speed vs Time graph between Stations A and C

It is evident from Figure 9 that:

$$t_{AC} = t_{AB} + S + t_{BC} \tag{7}$$

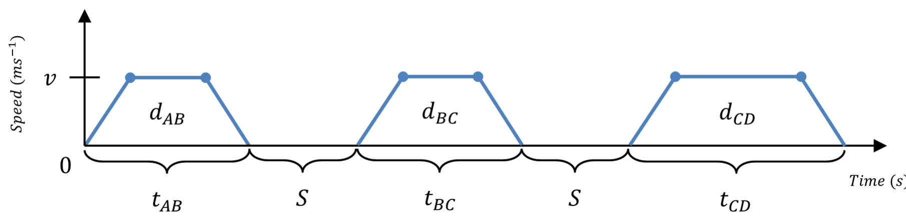

Figure 10 - Speed vs Time graph between Stations A and D

Similarly, Figure 10 provides the expression for t_{AD} as:

$$t_{AD} = t_{AB} + S + t_{BC} + S + t_{CD} \tag{8}$$

5.2 *Snowpiercer*'s Travel Time

Assuming all passengers take full advantage of the "passing through" carriage(s), the graph representing a *Snowpiercer* passenger making the journey from Station A to D is represented as:

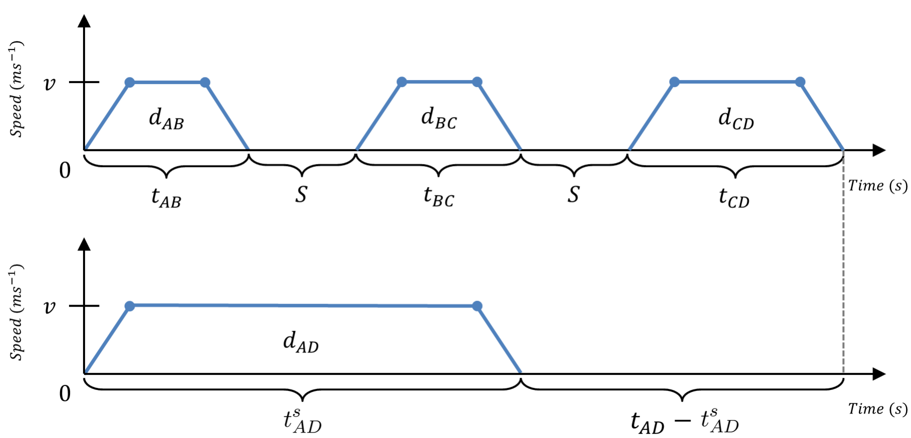

Figure 11 - Speed vs Time graph between Stations A and D;
repeat of Figure 10 (top),
hypothetical *Snowpiercer* passenger (bottom)

In Figure 11, we introduced a new quantity, t^s_{AD}, representing the travel time for a *Snowpiercer* passenger journeying from Station A to D. Using this figure alongside Equation 6, we can compute the travel time difference between traditional and Snowpiercer operations:

$$
\begin{aligned}
t_{AD} - t^s_{AD} &= t_{AB} + S + t_{BC} + S + t_{CD} - t^s_{AD} \\
&= \left(\frac{d_{AB}}{v} + \frac{v}{a}\right) + \left(\frac{d_{BC}}{v} + \frac{v}{a}\right) + \left(\frac{d_{CD}}{v} + \frac{v}{a}\right) + 2S \\
&- \left(\frac{d_{AD}}{v} + \frac{v}{a}\right) \\
&= \frac{d_{AD}}{v} + 3\frac{v}{a} + 2S - \frac{d_{AD}}{v} - \frac{v}{a} \\
&= 2\frac{v}{a} + 2S
\end{aligned}
\tag{9}
$$

In general, the total time saved by employing *Snowpiercer* over conventional stop-based operations scales with the number of intermediate stations n:

$$\Delta t = n\left(\frac{v}{a} + S\right)$$

This result implies that the performance gains from *Snowpiercer* increase linearly with the number of skipped stops. Notably, it follows directly that the model offers no advantage for travel between two consecutive stations.

More importantly, this model is most impactful in dense transit networks characterized by short interstation distances and frequent stops — a profile typical of intracity services.

In the following chapters, we examine hypothetical implementations of the *Snowpiercer* system in two contrasting scenarios: (1) a dense, low-speed intracity network, and (2) an intercity high-speed rail corridor.

6 Proposed Implementation – Singapore MRT

The Singapore Mass Rapid Transit (MRT) system is selected as the first case study for evaluating the *Snowpiercer* model. Beyond its suitability as a dense, electrified network using Electric Multiple Units (EMUs), the MRT holds particular relevance to the author, having grown up in Singapore and relied on this system as a primary mode of transport for most of his life.

With an average daily ridership of 3.45 million[7] in a nation of 5.92 million people[8], the MRT is central to the urban mobility of Singapore. Its operational scale, technological infrastructure, and the progressive outlook of its transport authorities[9] make it a strong candidate for exploring modular train operations via dynamically coupled and decoupled carriages.

6.1 North-South Line

The North-South Line of the Singapore MRT spans from Jurong East in the west, through the northern region at Woodlands, and continues southward along the country's central spine to Marina South Pier. Its route forms a rough arc resembling a lowercase "n". Like all MRT lines, the North-South Line operates bidirectionally.

This line was selected due to its critical role in transporting working-class commuters between high-density residential areas—such as Woodlands, Yishun, and Toa Payoh—and the Central Business District (CBD), with key destination stations including City Hall and Raffles Place.

The North-South Line is highlighted in red in Figures 12 and 13. Its ridership concentration and directional commuter flows make it an ideal candidate for evaluating the potential time savings and congestion relief offered by the *Snowpiercer* model.

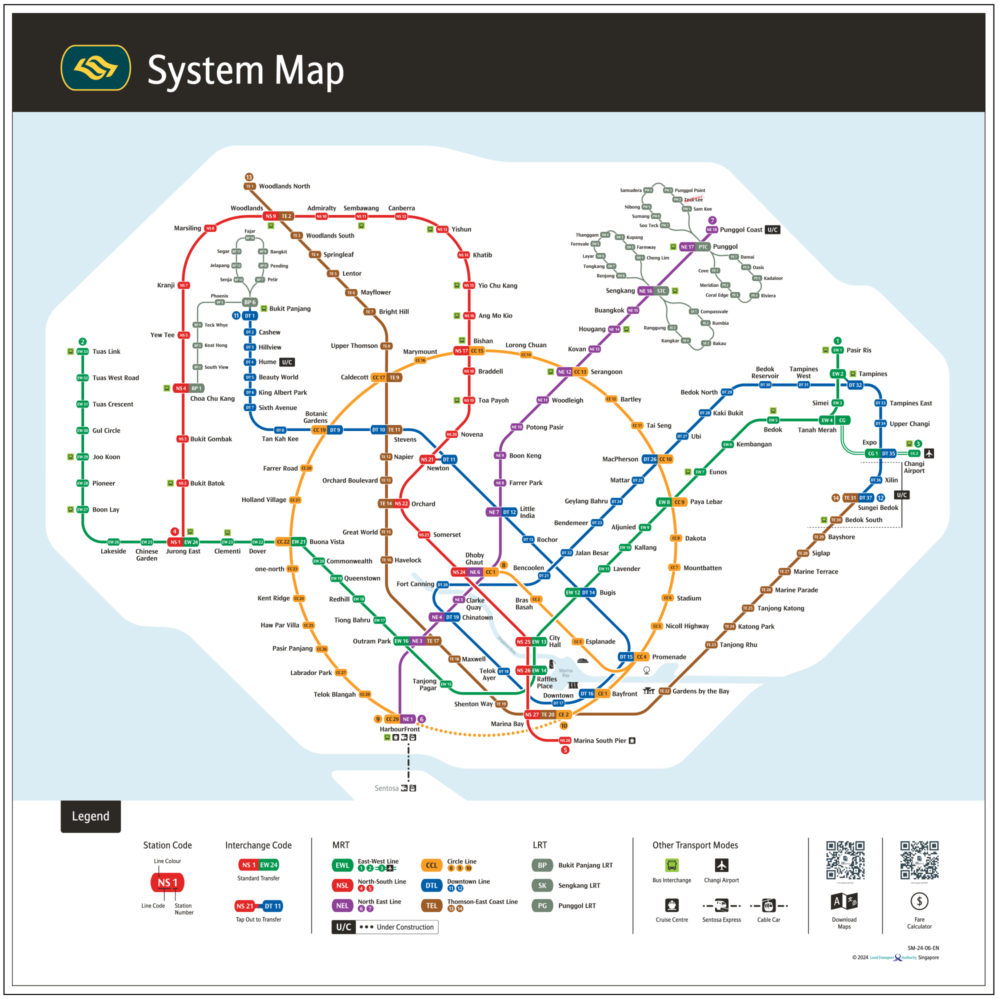

Figure 12 - Singapore MRT network map[10]

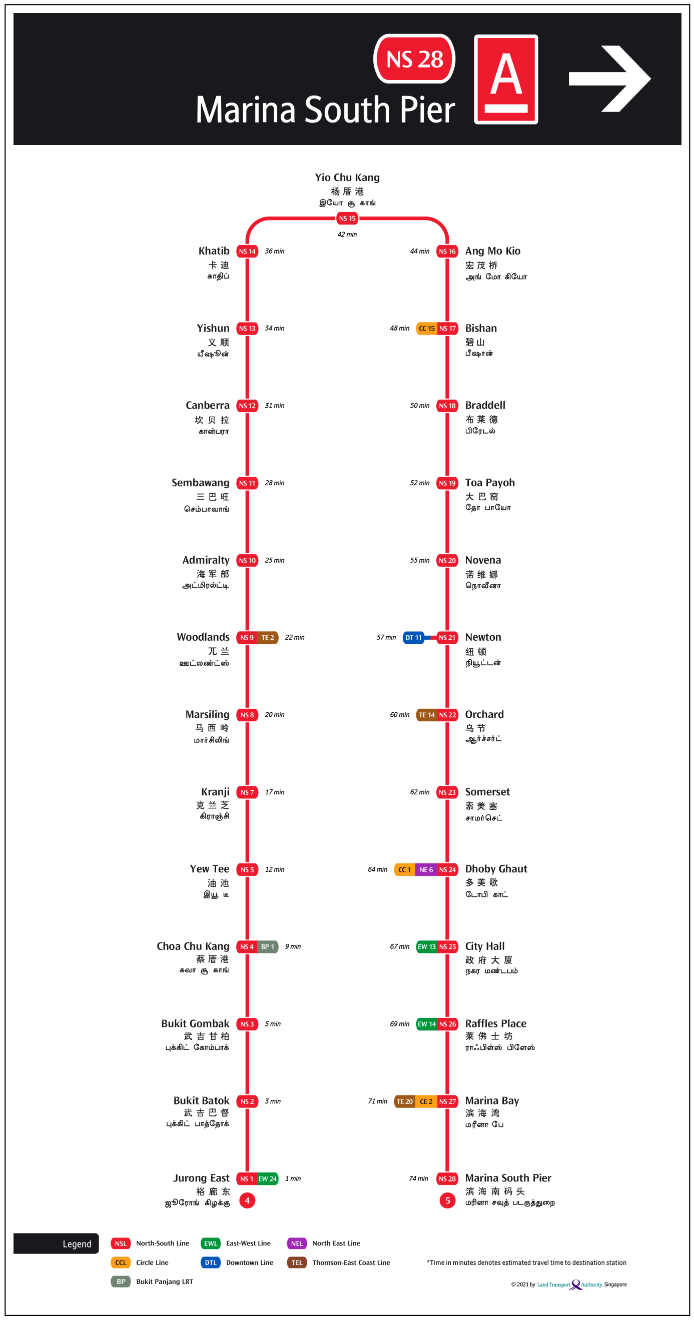

Figure 13 - North-South Line stations and official travel times

6.2 Official Statistics

To evaluate the potential efficiency gains enabled by the *Snowpiercer* model, we must first establish a detailed baseline of the North-South Line's current operations. Figure 14 compiles official data on track distances[11] and scheduled travel times[12], providing the foundation for subsequent comparative analysis.

Code	Station Name	Distance from previous station (m)	Official travel time (min)	
			prev station	cumulative
NS 1	Jurong East			
NS 2	Bukit Batok	2100	2	2
NS 3	Bukit Gombak	1200	2	4
NS 4	Choa Chu Kang	3300	4	8
NS 5	Yew Tee	1400	3	11
NS 7	Kranji	4100	5	16
NS 8	Marsiling	1700	3	19
NS 9	Woodlands	1500	2	21
NS 10	Admiralty	1700	3	24
NS 11	Sembawang	2400	3	27
NS 12	Canberra	1500	3	30
NS 13	Yishun	1700	3	33
NS 14	Khatib	1400	2	35
NS 15	Yio Chu Kang	4900	6	41
NS 16	Ang Mo Kio	1500	2	43
NS 17	Bishan	2400	4	47
NS 18	Braddell	1200	2	49
NS 19	Toa Payoh	900	2	51
NS 20	Novena	1500	3	54
NS 21	Newton	1200	2	56
NS 22	Orchard	1200	3	59
NS 23	Somerset	1000	2	61
NS 24	Dhoby Ghaut	800	2	63
NS 25	City Hall	1000	3	66
NS 26	Raffles Place	1000	2	68
NS 27	Marina Bay	1000	2	70
NS 28	Marina South Pier	1400	3	73

Figure 14 - Official North-South Line track distance and travel times

6.3 Modelling Current Hardware

As established in Chapter 5.1, the following parameters are required to compute travel times between stations:

- a – acceleration in ms^{-2}
- v – cruising speed in ms^{-1}
- d – track distance in m
- S – stoppage time in s

While official data for d is available, the remaining parameters are not directly provided by transit authorities. We therefore estimate a, v, and S using Equation 8—our baseline travel time model—alongside informed value ranges from related literature and operational reports[13].

$$a = 0.6ms^{-2} \tag{10}$$

$$v = 20ms^{-1} \tag{11}$$

$$S = 50s \tag{12}$$

Using these estimated values together with the official track distances, we construct a representative model of North-South Line travel times, as shown in Figure 15. The column "Estimated travel time" in this figure is computed using Equation 8 with the four parameters listed above.

Code	Station Name	Official travel time (min)	Estimated travel time (min)	% error
NS 1	Jurong East			
NS 2	Bukit Batok	2	2.31	30.56%
NS 3	Bukit Gombak	4	4.69	17.36%
NS 4	Choa Chu Kang	8	8.83	10.42%
NS 5	Yew Tee	11	11.39	3.54%
NS 7	Kranji	16	16.19	1.22%
NS 8	Marsiling	19	19.00	0.00%
NS 9	Woodlands	21	21.64	3.04%
NS 10	Admiralty	24	24.44	1.85%
NS 11	Sembawang	27	27.83	3.09%
NS 12	Canberra	30	30.47	1.57%
NS 13	Yishun	33	33.28	0.84%
NS 14	Khatib	35	35.83	2.38%
NS 15	Yio Chu Kang	41	41.31	0.75%
NS 16	Ang Mo Kio	43	43.94	2.20%
NS 17	Bishan	47	47.33	0.71%
NS 18	Braddell	49	49.72	1.47%
NS 19	Toa Payoh	51	51.86	1.69%
NS 20	Novena	54	54.50	0.93%
NS 21	Newton	56	56.89	1.59%
NS 22	Orchard	59	59.28	0.47%
NS 23	Somerset	61	61.50	0.82%
NS 24	Dhoby Ghaut	63	63.56	0.88%
NS 25	City Hall	66	65.78	-0.34%
NS 26	Raffles Place	68	68.00	0.00%
NS 27	Marina Bay	70	70.22	0.32%
NS 28	Marina South Pier	73	72.78	-0.30%

Figure 15 - Estimated North-South Line travel times based on $a = 0.6ms^{-2}$, $v = 20ms^{-1}$, and $S = 50s$

6.4 *Snowpiercer* Travel Time

With essential parameters established, we can now calculate hypothetical travel times should *Snowpiercer* be implemented on the North-South Line.

Code	Station Name	Traditional travel time (min)	Snowpiercer travel time (min)	% Difference
NS 1	Jurong East			
NS 2	Bukit Batok	2.31	2.31	0.00%
NS 3	Bukit Gombak	4.69	3.31	29.59%
NS 4	Choa Chu Kang	8.83	6.06	31.45%
NS 5	Yew Tee	11.39	7.22	36.59%
NS 7	Kranji	16.19	10.64	34.31%
NS 8	Marsiling	19.00	12.06	36.55%
NS 9	Woodlands	21.64	13.31	38.51%
NS 10	Admiralty	24.44	14.72	39.77%
NS 11	Sembawang	27.83	16.72	39.92%
NS 12	Canberra	30.47	17.97	41.02%
NS 13	Yishun	33.28	19.39	41.74%
NS 14	Khatib	35.83	20.56	42.64%
NS 15	Yio Chu Kang	41.31	24.64	40.35%
NS 16	Ang Mo Kio	43.94	25.89	41.09%
NS 17	Bishan	47.33	27.89	41.08%
NS 18	Braddell	49.72	28.89	41.90%
NS 19	Toa Payoh	51.86	29.64	42.85%
NS 20	Novena	54.50	30.89	43.32%
NS 21	Newton	56.89	31.89	43.95%
NS 22	Orchard	59.28	32.89	44.52%
NS 23	Somerset	61.50	33.72	45.17%
NS 24	Dhoby Ghaut	63.56	34.39	45.89%
NS 25	City Hall	65.78	35.22	46.45%
NS 26	Raffles Place	68.00	36.06	46.98%
NS 27	Marina Bay	70.22	36.89	47.47%
NS 28	Marina South Pier	72.78	38.06	47.71%

Figure 16 - *Snowpiercer* vs Traditional travel times (table)

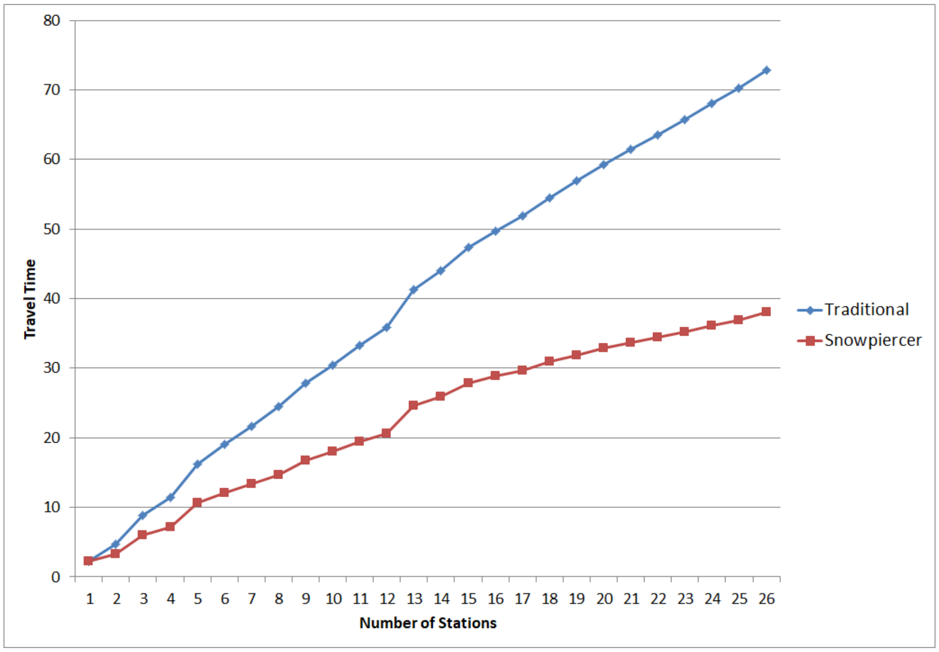

Figure 17 - *Snowpiercer* vs Traditional travel times (graph)

Figures 16 and 17 extend the analytical framework presented in Figure 11 and Equation 9 to the full scale of the North-South Line. While Chapter 5.1 examined a simplified case involving four consecutive stations, these figures depict cumulative time savings across all 27 stations of the line, reflecting a realistic dense urban railway scenario.

To illustrate the potential benefits of the *Snowpiercer* model, we highlight two representative high-traffic routes commonly used by working-class commuters. One such route is from Yishun to City Hall, spanning 12 stations. Let t denote the total travel time under traditional operations, and t^s represent the corresponding time under the *Snowpiercer* model:

$$\begin{aligned} t &= 31m\ 40s \\ t^s &= 16m\ 24s \\ t - t^s &= 15m\ 16s \\ \left(\frac{t - t^s}{t}\right) \cdot 100\% &= 48.25\% \end{aligned} \tag{13}$$

This nearly 50% reduction in travel time underscores the substantial efficiency gains possible in high-density urban corridors when using dynamically coupled carriage systems.

Similarly from Toa Payoh to City Hall (6 stations),

$$\begin{aligned} t &= 13m\ 5s \\ t^s &= 6m\ 8s \\ t - t^s &= 6m\ 57s \\ \left(\frac{t - t^s}{t}\right) \cdot 100\% &= 53.08\% \end{aligned} \tag{14}$$

From Equations 13 and 14, and as illustrated in Figure 16, we conservatively estimate that the *Snowpiercer* model can achieve a 40% reduction in commute time on dense urban routes.

Assuming this reduction applies uniformly across the MRT's average daily ridership of 3.45 million passengers, and using Singapore's reported average MRT commute time of 41 minutes per passenger[14], we estimate the following total time savings:

$$\begin{aligned} \text{Daily Person-Minutes Saved} &= 3.45 \times 10^6 \times 41 \times 0.4 \\ &= 56.58 \times 10^6 \text{ min} \\ \text{Daily Person-Hours Saved} &= \frac{56.58 \times 10^6}{60} = 943{,}000 \text{ h} \end{aligned} \tag{15}$$

Annualized across 365 days:

$$\text{Annual Person-Hours Saved} = 943{,}000 \times 365 = 344{,}195{,}000 \text{ h} \tag{16}$$

These figures highlight the transformative potential of the *Snowpiercer* model when applied to high-density commuter rail systems. Even under conservative assumptions, the model offers an estimated 40% reduction in travel time—translating to approximately 344 million person-hours saved annually across the entire MRT network.

The substantial time savings demonstrated—on the order of hundreds of millions of person-hours annually—underscore the transformative potential of the *Snowpiercer* model for urban rail systems like Singapore's MRT. However, achieving these gains in practice requires more than conceptual scheduling changes; it necessitates a new operational architecture that leverages the full flexibility of dynamically coupled carriages.

In the following section, we explore how *Snowpiercer* can be implemented at the station level by introducing the concept of *dynamic station capacity*, a mechanism that enables simultaneous boarding, alighting, and through-passage operations within a single station footprint. We begin with a visual aid designed to build intuition around this scheduling model.

6.5 Dynamic Station Capacity — MRT

Building on the projected time savings discussed in the previous section, we now explore a practical implementation of the *Snowpiercer* model within the Singapore MRT system. Central to this implementation is the concept of *dynamic station capacity*—the ability of a station to handle multiple train interactions (boarding, alighting, and through-passage) simultaneously by leveraging modular train operations.

To facilitate understanding of the complex scheduling logic required, we begin with a visual framework designed to illustrate the flow and coordination of dynamically coupled and decoupled carriages across consecutive stations.

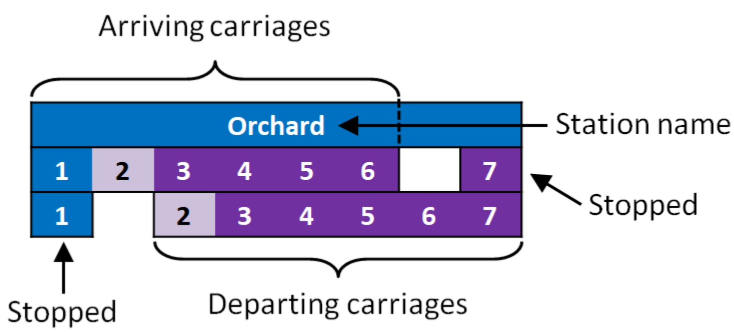

Figure 18 - Station schedule example 1

Breakdown of the station schedule depicted in Figure 18:

- We read the station schedule from top to bottom, noting this station name is Orchard, and its **colour theme** is white text on a blue background.
- The station's colour theme can be gleaned from the topmost row that contains the station name. The necessity of this feature will be apparent shortly.
- The second and third row represent the station's carriage state before and after a train passing through the station respectively. The trains/carriages travel from left to right.

- Row 2 – the carriage stopped at the station is identified as carriage [7], while the arriving carriages are [1, 2, 3, 4, 5, 6].
- Row 2 – we can tell that Orchard station hosts **1** carriage, while the service runs a phantom train of length **6**.
- We infer from rows 2 and 3 that [1] will dynamically decouple from the non-stopping carriages [2, 3, 4, 5, 6], while [7] will accelerate and dynamically couple with the departing train, forming [2, 3, 4, 5, 6, 7].
- Upon [1] having stopped and [2, 3, 4, 5, 6, 7] having departed, we are effectively back to the configuration of row 2. [1] will now take on the role of [7] while it awaits the next train.

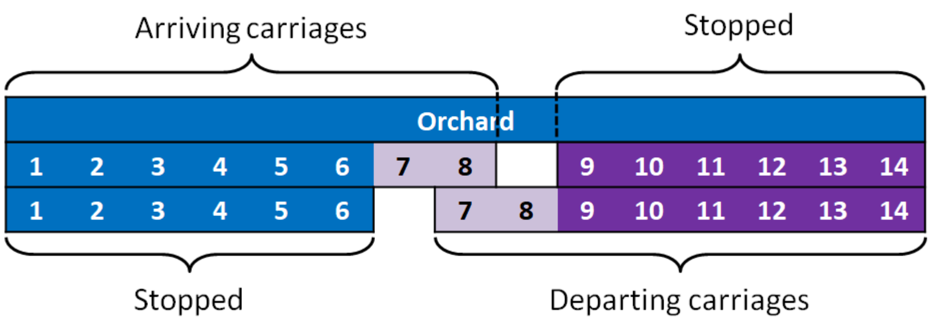

Figure 19 - Station schedule example 2

Figure 19 retains most of the features described in Figure 18, its main difference being that Orchard is now a "bigger" station, hosting **6** carriages, while the service runs a phantom train of length **8**.

Before viewing the combined station schedules of a network, the importance of a station's **colour theme** must first be emphasised. From Figure 19, carriages [1, 2, 3, 4, 5, 6] possess the same theme as this station Orchard. This is no coincidence as these carriages are bound for this station, just as [7, 8] are bound for a lavender-coloured station, and carriages [9, 10, 11, 12, 13, 14] are bound for a purple-coloured station.

This colour-coding of a carriage's "destined" station aids greatly in navigating more complex schedules of multiple stations. In Figure 20 below, we illustrate the schedule of a truncated portion of the North-South Line.

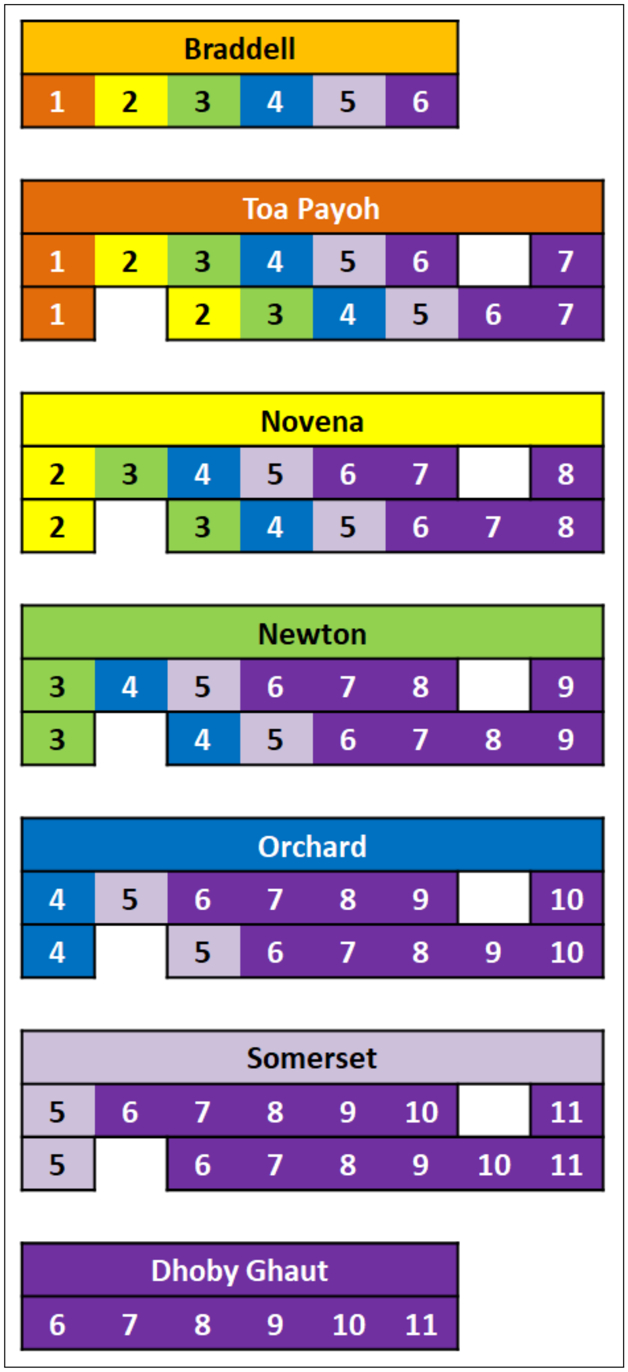

Figure 20 - Station schedule from Braddell to Dhoby Ghaut (1)

Breakdown of Figure 20:

- Reading from top to bottom, Braddell is the origin station and Dhoby Ghaut is the terminal station, hence their capacity is the same as the phantom train length of **6** carriages. Arrivals and departures at these stations do not involve dynamic coupling or decoupling.

- Apart from the origin and terminal, the other five stations have a capacity of **1** carriage. We can thus represent the service's carriage configuration with the shorthand [6-1-1-1-1-1-6].

- It is obvious that carriages terminating at Dhoby Ghaut form a majority in this schedule. As this [6-1-1-1-1-1-6] configuration is intended only for illustration, it would only make sense if Dhoby Ghaut is a popular destination for passengers evenly distributed between Braddell and Somerset.

- A passenger boarding from any station before Dhoby Ghaut is guaranteed a carriage terminating at Dhoby Ghaut, which is very handy if Dhoby Ghaut is a popular destination.

- A passenger boarding at the origin Braddell is guaranteed a direct carriage to **all** stations – very convenient indeed.

- Unfortunately, *Snowpiercer* isn't all sunshine and roses. Consider a passenger boarding at Newton and intending to alight at the next stop, Orchard. Studying the Newton station schedule, the passenger is expected to traverse **five** carriages, from [9] to [4] in the time span of just one station.

- This seemingly inconvenient passenger journey is mitigated by three factors – (1) such short journeys between low-traffic stations being infrequent, (2) the implementation of *Snowpiercer* will likely increase train frequency, allowing for uncrowded carriages thus easing transfer, and (3) passengers are aided by the non-stopping nature of *Snowpiercer*, which means the transfer carriages do not accelerate or decelerate, providing a stable and smooth platform for passenger transfer.

- Lastly, consider a passenger boarding at Newton and intending to alight two stops later at Somerset. This passenger has a relatively simple requirement of traversing just **four** carriages in the span of two stations.

In addition to hosting different numbers of carriages at different stations based on passenger demand, *Snowpiercer* also enables the phantom train to comprise **more** carriages than existing station capacities.

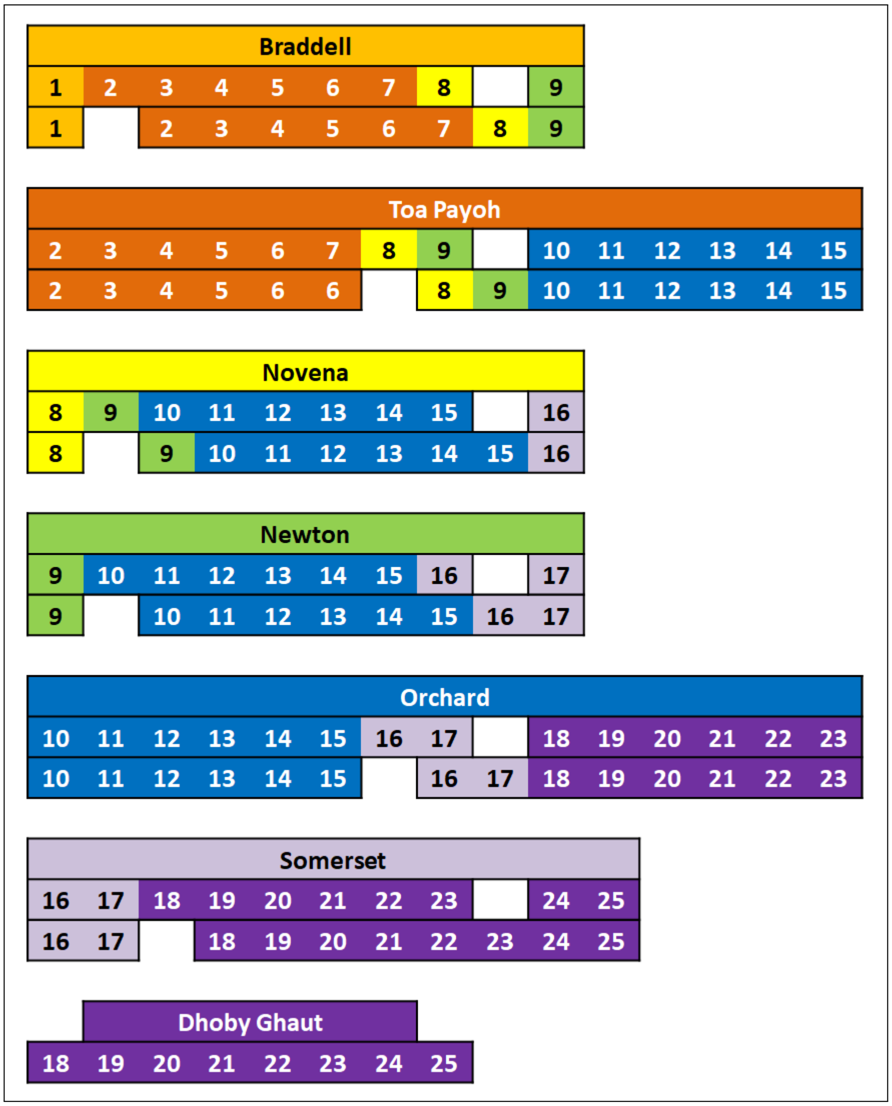

Figure 21 - Station schedule from Braddell to Dhoby Ghaut (2)

Breakdown of Figure 21:

- This time, Braddell is not the origin while Dhoby Ghaut remains the terminal. Accounting for all other station capacities, the service's configuration is now [...-1-6-1-1-6-2-8], with a phantom train length of **8** carriages.
- In reality, the stations on the North-South Line have a carriage capacity of **6**. This schedule takes advantage of the phantom train's transient nature to allow for a train with more carriages than any station can host.
- It is evident that the number of carriages bound for any station is directly proportional to that station's carriage capacity.
- In this schedule, Toa Payoh and Orchard are assessed to be high-traffic stations thus allotted 6 carriages.
- A passenger travelling from Toa Payoh to Orchard can simply board any carriage as they are all bound for Orchard. Similarly in Orchard, all carriages are bound for Dhoby Ghaut.
- A passenger travelling from Orchard to Somerset can strategically board carriage [18] and simply make a one-carriage transfer to the Somerset-bound carriage [17].
- A passenger travelling from Toa Payoh to Somerset will however be required to transfer before reaching Orchard. This passenger can transfer to any of the two lavender-coloured carriages having coupled from both Novena and Newton. A more nuanced strategy would be to board carriage [10] at Toa Payoh, so that transferring to a Somerset-bound carriage will involve crossing fewer carriages.
- A passenger travelling from Braddell to Dhoby Ghaut will require a minimum of two transfers. Boarding a Newton-bound carriage, this passenger will transfer to a Somerset-bound carriage once past Novena. A final transfer will be required once past Orchard.
- While popular routes are served with minimal or no transfers, passengers are presumed to be willing to perform their necessary transfers as a trade-off for the significant travel time saved.

The visual frameworks and accompanying explanations in this section demonstrate how dynamic station capacity enables the continuous movement of trains through busy transit nodes without sacrificing passenger accessibility. By decoupling the traditional link between full-train stoppages and boarding events, the *Snowpiercer* model introduces a new operational layer that flexibly scales with passenger volume and directional demand. Applied to the Singapore MRT, this capability suggests not only significant time savings, but also a reimagining of station design and train scheduling that better aligns with the demands of dense urban mobility.

Having established the viability of this approach in a metropolitan intracity setting, we now turn to the *Tōkaidō Shinkansen*—a pioneering high-speed rail corridor—to examine how the Snowpiercer concept might translate to longer-distance, intercity applications.

7 Proposed Implementation — Shinkansen

The Tōkaidō Shinkansen, inaugurated in 1964 as the world's first high-speed rail line, revolutionized intercity passenger transport and remains among the most heavily used and punctual rail corridors globally. Its significance and historical impact make it a natural candidate for examining the applicability of the *Snowpiercer* model in a high-speed, long-distance context.

In this section, we assess how the operational assumptions and benefits of dynamic coupling and decoupling translate to the distinct characteristics of intercity travel—longer station gaps, higher speeds, and greater acceleration and deceleration constraints.

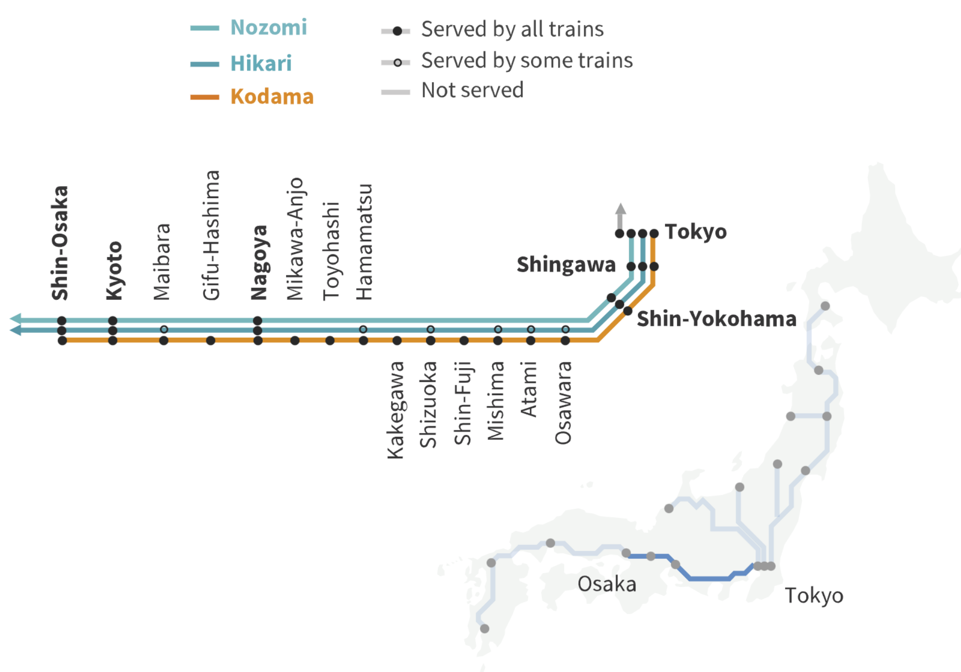

Figure 22 - Tōkaidō Shinkansen Map[6]

7.1 Nozomi vs. Kodama

The Tōkaidō Shinkansen operates three primary service types: Nozomi, Hikari, and Kodama. Nozomi is the fastest, making the fewest stops between Tokyo and Shin-Osaka, while Kodama is the most localized, stopping at nearly every station along the route. Hikari lies between the two in terms of speed and stop frequency.

For this analysis, we focus on the Nozomi and Kodama services as representative extremes—express and local operations—allowing us to evaluate the potential impact of the *Snowpiercer* model across varying station densities.

Including origin and terminal stations, Nozomi makes **6** stops, whereas Kodama makes **17**. Figures 23 and 24 present the station sequences for both services, along with corresponding track distances and official travel times[16].

Station Name (Nozomi)	Distance from previous station (km)	Distance from Tokyo (km)	Official travel time from Tokyo (min)	Official travel time from previous station (min)
Tokyo				
Shinagawa	6.8	6.8	8	8
Shin-Yokohama	18.7	25.5	19	11
Nagoya	316.5	342	101	82
Kyoto	134.3	476.3	136	35
Shin-Osaka	39.1	515.4	150	14

Figure 23 - Official Nozomi stations, track distances, and travel times

Station Name (Kodama)	Distance from previous station (km)	Distance from Tokyo (km)	Official travel time from Tokyo (min)	Official travel time from previous station (min)
Tokyo				
Shinagawa	6.8	6.8	7	7
Shin-Yokohama	18.7	25.5	18	11
Odawara	51.2	76.7	38	20
Atami	18.7	95.4	46	8
Mishima	15.9	111.3	58	12
Shin-Fuji	23.7	135	71	13
Shizuoka	32.4	167.4	84	13
Kakegawa	43.9	211.3	99	15
Hamamatsu	27.6	238.9	114	15
Toyohashi	35.3	274.2	131	17
Mikawa-Anjo	38.6	312.8	148	17
Nagoya	29.2	342	166	18
Gifu-Hashima	25.1	367.1	181	15
Maibara	41.1	408.2	199	18
Kyoto	68.1	476.3	219	20
Shin-Osaka	39.1	515.4	234	15

Figure 24 - Official Kodama stations, track distances, and travel times

7.2 Modelling Current Hardware

Using widely available technical specification on the N700 Series Shinkansen[15], we arrive at the estimates for the essential variables:

$$a = 0.27ms^{-2} \tag{17}$$

$$v = 76ms^{-1} \tag{18}$$

$$S = 170s \tag{19}$$

Using these variables, we can model both the Nozomi and Kodama services with moderate accuracy as shown in Figures 25 and 26 below.

Station Name (Nozomi)	Official travel time from Tokyo (min)	Estimated time from Tokyo (min)	% error
Tokyo			
Shinagawa	8	8.1	1.54%
Shin-Yokohama	19	19.7	3.94%
Nagoya	101	96.7	-4.28%
Kyoto	136	133.7	-1.72%
Shin-Osaka	150	149.8	-0.16%

Figure 25 - Estimated Nozomi travel times based on $a = 0.27ms^{-2}$, $v = 76ms^{-1}$, $S = 170s$

Station Name (Kodama)	Official travel time from Tokyo (min)	Estimated time from Tokyo (min)	% error
Tokyo			
Shinagawa	7	8.1	16.05%
Shin-Yokohama	18	19.7	9.72%
Odawara	38	38.5	1.32%
Atami	46	50.1	8.97%
Mishima	58	61.1	5.41%
Shin-Fuji	71	73.9	4.03%
Shizuoka	84	88.5	5.35%
Kakegawa	99	105.6	6.71%
Hamamatsu	114	119.2	4.58%
Toyohashi	131	134.5	2.66%
Mikawa-Anjo	148	150.5	1.67%
Nagoya	166	164.4	-0.96%
Gifu-Hashima	181	177.4	-1.97%
Maibara	199	194.0	-2.53%
Kyoto	219	216.4	-1.17%
Shin-Osaka	234	232.5	-0.63%

Figure 26 - Estimated Kodama travel times based on $a = 0.27ms^{-2}$, $v = 76ms^{-1}$, $S = 170s$

7.3 *Snowpiercer* Travel Time

With essential parameters established, we now calculate hypothetical travel times should *Snowpiercer* be implemented on both Nozomi and Kodama.

Station Name (Nozomi)	Estimated time from Tokyo		Snowpiercer time from Tokyo		% Difference
	s	min	s	min	
Tokyo					
Shinagawa	487.4	8.1	487.4	8.1	0.00%
Shin-Yokohama	1184.9	19.7	787.0	13.1	33.58%
Nagoya	5800.9	96.7	4951.5	82.5	14.64%
Kyoto	8019.5	133.7	6718.6	112.0	16.22%
Shin-Osaka	8985.4	149.8	7233.1	120.6	19.50%

Figure 27 - *Snowpiercer* vs Traditional Nozomi travel times (table)

Station Name (Kodama)	Estimated time from Tokyo		Snowpiercer time from Tokyo		% Difference
	s	min	s	min	
Tokyo					
Shinagawa	487.4	8.1	487.4	8.1	0.00%
Shin-Yokohama	1184.9	19.7	787.0	13.1	33.58%
Odawara	2310.1	38.5	1460.7	24.3	36.77%
Atami	3007.6	50.1	1706.7	28.4	43.25%
Mishima	3668.3	61.1	1916.0	31.9	47.77%
Shin-Fuji	4431.6	73.9	2227.8	37.1	49.73%
Shizuoka	5309.4	88.5	2654.1	44.2	50.01%
Kakegawa	6338.6	105.6	3231.7	53.9	49.01%
Hamamatsu	7153.2	119.2	3594.9	59.9	49.74%
Toyohashi	8069.2	134.5	4059.4	67.7	49.69%
Mikawa-Anjo	9028.5	150.5	4567.3	76.1	49.41%
Nagoya	9864.2	164.4	4951.5	82.5	49.80%
Gifu-Hashima	10646.0	177.4	5281.7	88.0	50.39%
Maibara	11638.2	194.0	5822.5	97.0	49.97%
Kyoto	12985.8	216.4	6718.6	112.0	48.26%
Shin-Osaka	13951.7	232.5	7233.1	120.6	48.16%

Figure 28 - *Snowpiercer* vs Traditional Kodama travel times (table)

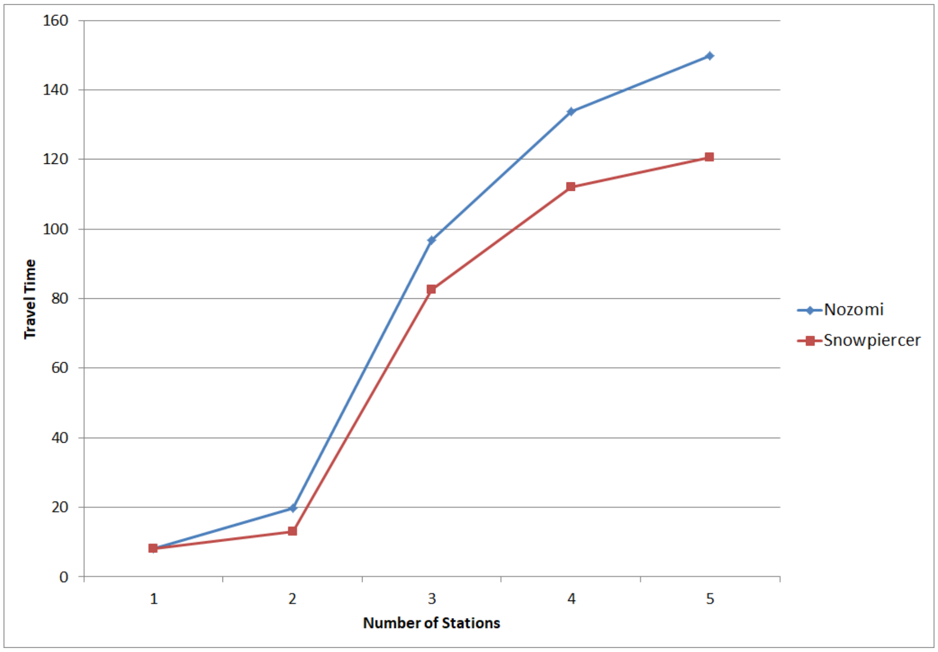

Figure 29 - *Snowpiercer* vs Traditional Nozomi travel times (graph)

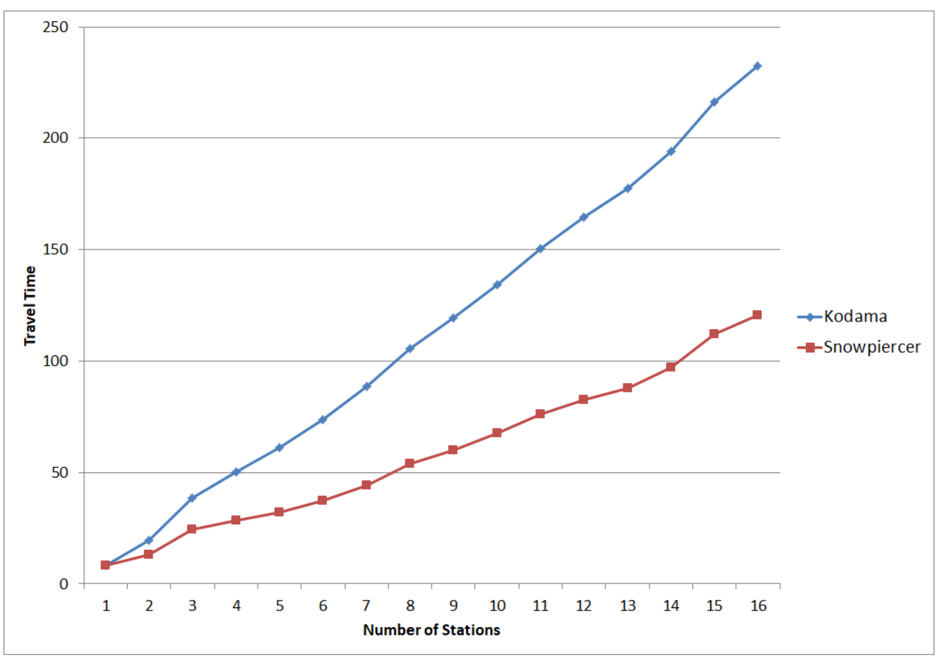

Figure 30 - *Snowpiercer* vs Traditional Kodama travel times (graph)

Figures 27 through 30 make clear that the *Snowpiercer* model yields greater efficiency gains on rail services with frequent stops and diminishing returns on high-speed express routes.

For the journey from Tokyo to Shin-Osaka, Nozomi's travel time is reduced from 150 minutes to 121 minutes, a 19.5% reduction. In contrast, Kodama sees its journey time drop from 233 minutes to 121 minutes—a reduction of 48.16%.

Notably, both services converge to the same final travel time of approximately 120.6 minutes. This convergence arises from a fundamental property of the *Snowpiercer* system: the ability to bypass intermediate stations dynamically, rendering the number of stops along the route largely irrelevant. In networks with dense station spacing—such as those served by Kodama—the potential for time savings is significantly greater due to the higher number of bypassed stops.

Assuming a daily Shinkansen ridership of 1 million passengers[17], an average journey duration of 2 hours[18], and conservatively estimating a 30% reduction in travel time, we estimate the following time savings:

$$\begin{aligned} \text{Daily Person-Hours Saved} &= 1 \times 10^6 \cdot 2 \cdot 0.3 \\ &= 600{,}000 \text{ h} \end{aligned} \tag{20}$$

Annualized across 365 days:

$$\text{Annual Person-Hours Saved} = 600{,}000 \cdot 365 = 219{,}000{,}000 \text{ h} \tag{21}$$

These results suggest that while high-speed intercity lines like the Shinkansen benefit less proportionally from *Snowpiercer*, the absolute savings remain significant, due to high passenger volumes and long journey durations.

7.4 Dynamic Station Capacity — Nozomi

While dynamic station capacity was previously examined in the context of Singapore's densely spaced MRT network, this section investigates its applicability to the sparser, high-speed Nozomi service on the Tōkaidō Shinkansen.

Although Nozomi makes relatively few stops, the concept of dynamic station operations remains relevant—particularly for optimizing throughput at major interchange stations or minimizing disruption from intermediate boarding and alighting. We explore how the modular scheduling principles of *Snowpiercer* can be adapted to meet the spatial and operational constraints of a high-speed intercity environment.

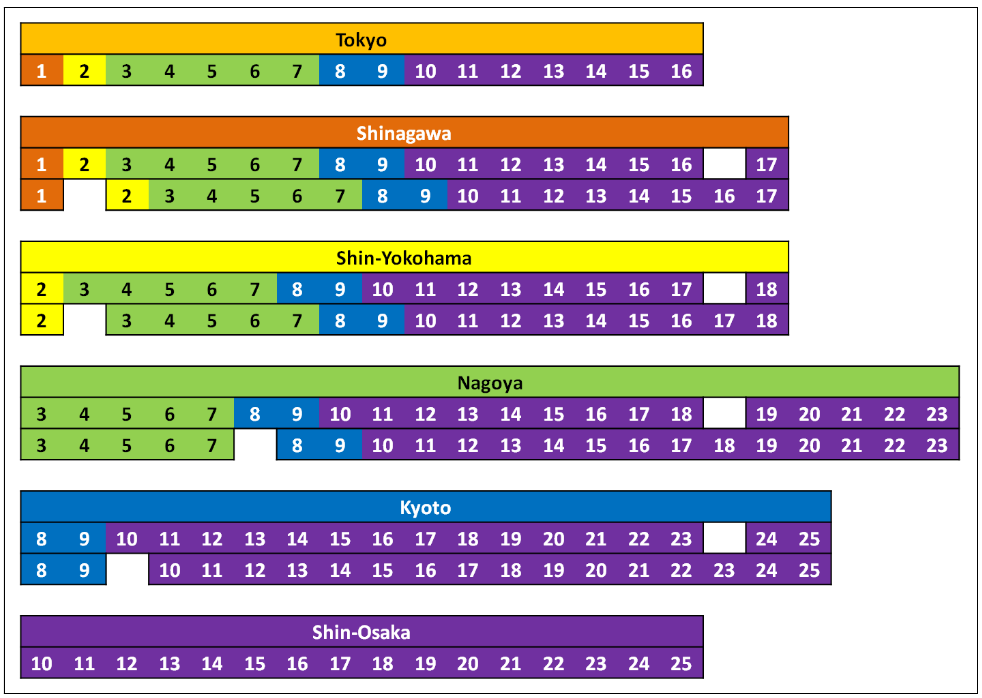

Figure 31 - Nozomi station schedule from Tokyo to Shin-Osaka

The Nozomi service operates with trains composed of 16 carriages[20], enabling modular segmentation of passengers by destination under a *Snowpiercer* configuration. As illustrated in Figure 31, a representative carriage allocation at Tokyo station might designate cars 10 through 16 for non-stop travel to Shin-Osaka, cars 3 through 7 to Nagoya, cars 8 and 9 to Kyoto, and cars 1 and 2 to intermediate stops at Shinagawa and Shin-Yokohama, respectively.

This configuration ensures that passengers headed to major intercity destinations benefit from uninterrupted travel within dedicated carriages, minimizing unnecessary dwell time or passenger congestion. In rare cases—such as a passenger traveling only from Shinagawa to Shin-Yokohama—a transfer across up to 15 carriages may be required within the 9-minute window defined by the segment's travel time. However, such edge cases are infrequent, and the train's extended length offers ample time and space for passengers to reposition if needed.

Compared to the Singapore MRT's six-carriage trains and tightly spaced stations, the Nozomi's longer train length and broader station intervals support destination-dedicated carriages without the urgency of rapid in-train transfers, allowing dynamic station capacity to be implemented with greater operational flexibility.

This case study underscores the adaptability of the *Snowpiercer* model to high-speed intercity contexts. Even in systems with relatively few stops, it offers meaningful advantages, including reduced dwell times, smoother passenger flows, and more efficient use of train capacity. This versatility highlights the model's broader applicability across multiple scales of railway infrastructure—setting the stage for a broader discussion of its implications, limitations, and potential future directions.

8 AI-Guided Scheduling and Control

8.1 Motivation for AI Integration

The modularity and dynamic behavior of the *Snowpiercer* model introduces a level of scheduling complexity that challenges conventional rail control systems. Traditional static timetables and rule-based signaling protocols are ill-suited for managing real-time decisions on coupling, decoupling, and rerouting. These challenges present an opportunity for the application of artificial intelligence (AI) in orchestrating operations at scale, while adapting to fluctuating passenger demand and network conditions.

8.2 Real-Time Carriage Allocation and Routing

A key aspect of *Snowpiercer*'s flexibility lies in its ability to allocate specific carriages to specific destinations dynamically. Traditional static timetables are insufficient to manage such complexity, particularly on bidirectional lines with variable demand.

Relevant work has already demonstrated the effectiveness of optimization models that integrate coupling-decoupling operations, rolling stock allocation, and capacity constraints into the full-day scheduling of intercity railways [19]. For example, a hybrid algorithm combining genetic methods with a truncated branch-and-cut approach has shown promising results in reducing both passenger wait times and operating costs on China's Shanghai–Hangzhou intercity line.

Inspired by such techniques, future implementations of the *Snowpiercer* model could leverage AI-driven optimization frameworks to make real-time routing and resource decisions across modular trains.

8.3 Conflict Resolution and Signalling

As multiple carriages are scheduled to merge or diverge across stations, the system must handle routing conflicts on shared tracks. AI can assist in real-time conflict resolution by predicting where coupling sequences may interfere with ongoing services and by proposing routing or timing adjustments to avoid bottlenecks. This would require integration with intelligent signalling systems capable of responding to high-resolution forecasts and constraints.

8.4 Passenger Flow Forecasting and Rebalancing

The effectiveness of Snowpiercer also depends on how well it matches carriage allocation with passenger flow. AI models could forecast boarding patterns at various stations, suggesting preemptive carriage reassignments or station skip strategies. These predictions could also improve safety by mitigating gangway congestion during transfers and ensuring even distribution of load across carriages.

8.5 Toward an Intelligent Modular Rail Network

In its most advanced form, Snowpiercer could evolve into a self-optimizing transport layer across a multi-line rail network. AI would manage not only local carriage dynamics but also inter-line carriage transfers, depot allocation, and system-wide efficiency. As real-time computation and rail infrastructure modernize, such a system could function much like a neural network—continuously optimizing passenger throughput, energy use, and scheduling fidelity.

9 Discussion and Conclusion

9.1 Discussion

Before concluding, we highlight several relevant topics that, due to scope constraints, were not addressed in depth within this paper but merit future investigation:

1. **Engineering feasibility** — While the dynamic coupling and decoupling of EMUs (such as those used on the MRT) is within current technological reach, the same cannot yet be said for high-speed trains like the Shinkansen. The aerodynamic requirements of leading cars—such as those on the N700 Series (see Figure 32)—pose significant challenges to mid-journey reconfiguration at cruising speeds exceeding 300 km/h. The mechanical, safety, and control-system hurdles of implementing high-speed dynamic coupling remain a major area for future engineering research.

2. **Scheduling and signalling complexity** — Implementing a dynamic coupling and decoupling model across a national or regional rail system would introduce significant scheduling challenges. Unlike conventional trains with fixed stop patterns, the *Snowpiercer* model demands real-time updates to train composition, dwell time buffers, and track clearance. Coordinating these elements would likely require a more advanced signalling infrastructure—potentially incorporating AI-assisted traffic control or predictive analytics—to prevent bottlenecks or unsafe configurations.

3. **Cross-line dynamic routing** — The *Snowpiercer* model, as discussed thus far, assumes dynamic operations within a single service line. However, with sufficiently advanced scheduling and signalling systems, dynamically coupled carriages could traverse multiple lines across a broader rail network. Instead of requiring passengers to transfer at major interchange stations, entire carriages could be decoupled from one line and coupled onto another—forming continuous, direct-destination journeys across intersecting routes.

   This approach would elevate the utility of the Snowpiercer model from line-level optimization to network-wide orchestration. Carriages could be dynamically reassigned en route to serve emerging demand patterns or optimize passenger distribution across the entire system. For example, a carriage originating in a suburban line could seamlessly couple onto an express intercity line, delivering passengers to a different city center without requiring a platform transfer.

4. **Super-dynamic station capacity** — In earlier discussions, each station's capacity was treated as static, despite stations serving varying numbers of carriages. In principle, a station's effective capacity could be adjusted dynamically throughout the day. For example, in response to changing demand patterns, depots could dispatch longer trains—extending the *phantom train* concept—with additional carriages that decouple at select stations. To reduce service capacity, surplus carriages could be reabsorbed by terminal depots. With careful scheduling and bidirectional service symmetry, such dynamic fleet balancing could optimize resource utilization.

5. **Emergency scenarios and contingency planning** — The introduction of modular, decoupling carriages adds complexity to emergency response protocols. For instance, if a carriage fails to decouple or rejoin, or if an onboard issue requires rapid evacuation, contingency plans must account for the intermediate operational state of the train. This includes re-routing, manual overrides, and communication with passengers in segmented carriages. Ensuring system robustness and fail-safes for these edge cases is crucial for operational reliability and public trust.

6. **Passenger distribution behavior** — At high-demand stations served by multiple carriages, passengers may disproportionately board the first available carriage for their destination rather than distribute evenly across all designated options. This behavior could lead to localized congestion, particularly at gangways during transfers. Addressing this may require behavioral nudges such as signage, real-time platform indicators, or controlled access systems to encourage more balanced carriage usage and preserve transfer safety.

7. **Accessibility and inclusivity** — Passengers with mobility impairments may find transfer-heavy journeys challenging or prohibitive. To improve accessibility, one possible solution is to apply the concept of super-dynamic station capacity, dispatching longer trains at scheduled intervals that increase the likelihood of boarding a direct carriage without requiring mid-journey transfers.

8. **Fare structure and ticketing systems** — Current fare systems are designed around station-to-station travel on fixed-line services. A modular, dynamically reconfiguring system complicates pricing models, especially if passengers are allowed or encouraged to switch carriages mid-route. It raises questions about how to track and charge for partial segments, transfer events, or boarding direct vs. indirect carriages. Fare policy innovations, possibly involving distance-based or usage-tiered pricing, may be needed to support such systems equitably and efficiently.

Figure 32 - N700 Series Shinkansen[20]

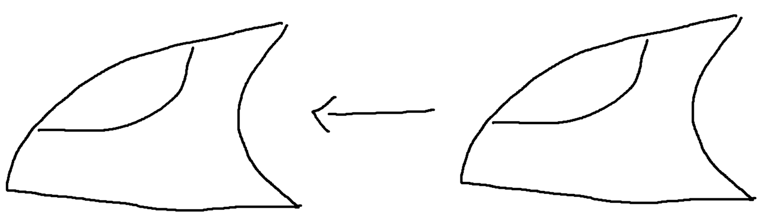

Figure 33 - Self-made illustration of the potential complexity in coupling high-speed rail carriages

9.2 Conclusion

The author extends sincere gratitude to the reader for engaging with this exploration of dynamically coupled railway systems. It is the author's hope that this work serves as an early contribution to a broader reimagining of high-efficiency, continuous-flow rail transport—one that challenges the traditional constraints of stop-based scheduling and station design.

The *Snowpiercer* model, while ambitious, offers a compelling vision for the future of passenger mobility. May this paper serve not as a final word, but as a starting point for continued innovation in the field of transportation systems engineering.

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