

LONG-TERM SERVICE, FLEET, AND ROBUSTNESS PLANNING FOR BALI LRT PHASE 1A AIRPORT ACCESS

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Abstract: Bali LRT Phase 1A is a planned 6.04-km airport rail connection from I Gusti Ngurah Rai International Airport to the Sunset Road area. Its Final Feasibility Study (FS) presents operating quantities at seven forecast horizons. This paper asks what sequence of operating decisions is implied when those quantities are read together. Using the FS as the only numerical source, demand-based service is reconstructed, applied headway is compared with that minimum, fleet needs are checked from the 29-min round-trip time, and transition timing is stressed at $\pm 10\%$ and $\pm 20\%$ demand. The seven horizons collapse into four service states: 10, 8, 7, and 6 min. Passenger fleet requirement follows 4, 5, 6, and 6 trainsets. The last step is therefore not another fleet-purchase point; service becomes denser with the same six passenger trainsets while the passenger-baggage route-conflict indicator reaches 31.51%. Demand deviation mainly changes the calendar. In the +20% case, thresholds associated with the baseline years 2039, 2049, and 2059 are crossed at about 2033, 2041, and 2044. For long-term planning, these results support treating the FS years as review points tied to observed demand rather than as fixed activation dates.

Keywords: airport ground access; airport rail; fleet planning; headway planning; robustness analysis

Introduction

In reviewing the FS, we did not treat seat capacity as the whole Phase 1A service question. The line is intended to feed an airport, so headway is also time added to the access chain before check-in or boarding. We therefore read frequency as both a capacity and a passenger-service variable. Ngurah Rai handled 24.1 million passenger movements in 2025, about 63% international, while congestion on the airport approaches remains recurrent. In that setting, the proposed rail link to Sunset Road offers not only additional transport capacity but also a potentially more predictable airport-access option (Bandara Internasional I Gusti Ngurah Rai, 2026; Kementerian Perhubungan Republik Indonesia, 2024; Nampu, 2024).

The corridor described in the FS is about 6.04 km long and has five passenger stations: Ngurah Rai Airport, Kuta, Pura Desa Adat, Central Park, and Sunset Road 01. Passenger trains run over the full corridor, whereas baggage trains share only the Ngurah Rai Airport-Central Park section. The numerical material used below is spread across the demand, operations, rolling-stock, route-conflict, and O&M parts of the report. We assemble those reported values for 2030-2059 without substituting a second operating dataset (Korea Export-Import Bank, 2024).

Relevant research approaches this planning problem from several directions. Airport ground-access studies focus on the way travel time, cost, transfers, reliability, and network changes affect

access choices and capacity. Using rail-transaction data, Wang et al. (2022) show that generalized travel attributes influence both airport and ground-rail choices. Avogadro et al. (2024) combine mode-choice modelling with microscopic traffic simulation to assess airport-access interventions, including direct rail access. In Indonesia, Setiawan et al. (2025) identify headway, frequency, service features, and minimum service standards as important elements of air-rail integration. Taken together, these studies indicate that an airport rail service must be judged by more than the number of passengers it can carry; the service offered to airport users also matters.

A second body of work examines how rail operations can respond to changing demand. Liu et al. (2023) design timetables for dynamic sectional passenger demand, Zhao et al. (2023) jointly consider timetables, train formation, and rolling-stock circulation, and Zhuo et al. (2024) link timetabling with rolling-stock scheduling. Wang et al. (2024) study flexible rolling-stock composition under time-varying demand and station-capacity constraints. For airport express services, He and Li (2024) relate train frequency to passenger-flow patterns and flight succession. These models offer detailed solutions once an operating condition has been specified. They are less concerned with the earlier planning decision faced here: when, over a multi-decade horizon, should a planned airport-rail corridor move from one service and fleet configuration to another?

Long-term rail studies address the timing problem from another angle. Wu and Schonfeld (2022) optimize phased development under demand, financing, and headway constraints, whereas Guo et al. (2023) examine how investment size and timing interact when demand is uncertain. Hrušovský et al. (2025) extend the time dimension to fleet sizing and fleet management. These studies are useful for thinking about staged decisions, but Phase 1A presents a narrower operational question. The alignment is held fixed; what changes over time is the service frequency, the number of passenger trainsets required, the intensity of passenger-baggage interaction, and the point at which procurement must be prepared.

Placing the literature beside the Bali FS exposes a specific planning gap. The report states what demand, service, fleet, and route interaction look like at seven forecast years, but it does not say what observed condition should trigger a move from one state to the next. A forecast year and a realized demand level are not the same thing. Reading those years as automatic activation dates creates a two-sided planning risk. Acting too early could bring forward rolling-stock procurement, O&M spending, and other resource commitments while demand is still below the intended service threshold, leaving assets underused. Acting too late could leave service below demand, increase waiting or crowding on an airport-access trip, weaken access reliability, and compress the lead time available for procurement and operational adjustment. We therefore treat the FS years as planning and review references, while activation decisions are tied to observed demand and operational evidence. We then read the reported changes by the demand level attached to them and check whether each change also alters fleet need or passenger-baggage interaction. The question addressed here is how to turn the FS snapshots into operating triggers without adding a second numerical dataset (Korea Export-Import Bank, 2024).

To examine that problem, we keep the FS numbers intact and reorganize them. The arithmetic capacity minimum, applied passenger service, fleet requirement, and passenger-baggage interaction are aligned by horizon. Three calculations then help interpret the sequence: the gap between applied and demand-based frequency, POB ratios at the later service changes, and a fleet cross-check based on RTT and headway. The same stage thresholds are tested with demand at -20%, -10%, +10%, and +20%. No additional operating dataset is introduced.

The study is organized around four questions: (RQ1) How can long-term demand growth for an airport-connected rail system be translated into successive passenger-service stages? (RQ2) At what demand levels do headway changes coincide with additional rolling-stock requirements? (RQ3) How does greater service density affect infrastructure interaction at the internal passenger-

baggage route-conflict points? (RQ4) How sensitive are service, fleet, and system-review transition timings to demand deviations of $\pm 10\%$ and $\pm 20\%$? The objective is to answer these questions through a reproducible strategic-to-tactical planning framework using one authoritative numerical source.

Table 1. Position of the study within airport-rail, demand-responsive rail, and long-term planning literature

Study	Demand representation	Main decision	Horizon	Staged transition
Liu et al. (2023)	Dynamic passenger flow	Timetable design	Operational	No
Zhao et al. (2023)	Time-dependent demand	Timetable + formation + circulation	Operational	No
Zhuo et al. (2024)	Time-dependent demand	Timetable + rolling stock	Operational	No
Wang et al. (2024)	Time-varying demand	Flexible rolling-stock composition	Operational	No
Guo et al. (2023)	Uncertain long-term demand	Rail investment timing + size	Strategic	Investment stages
Hrušovský et al. (2025)	Multi-year demand	Fleet size + management	Strategic/medium term	Fleet decisions
Wang et al. (2022)	Airport-access rail transactions	Airport + ground-rail choice	Behavioral/operational	No
Avogadro et al. (2024)	Traffic growth and access choice	Mode choice + airport-access intervention	Strategic to 2030	Intervention scenarios
He & Li (2024)	Passenger flow + flight succession	Airport-express timetable & frequency	Operational	No
Wu & Schonfeld (2022)	Elastic long-term demand	Phased rail development + headway	Strategic	Infrastructure stages
Setiawan et al. (2025)	Indonesian airport-rail service	Service features + MSS + satisfaction	Operational/policy	No
This study	FS forecasts, 2030-2059	Headway + fleet + infrastructure + robustness	Multi-decade	Yes

Note: The table compares the main decision represented in each study, its time horizon, and whether stages are explicitly modelled. The cited studies may also consider constraints outside the item shown here.

Method

1. Research design, data source, and analytical boundaries

We reanalyse the FS data over the full planning horizon. The Final Feasibility Study for Bali LRT Phase 1A is the only numerical source used in the analytical model. Other publications are used for context and literature positioning, but their numerical values are not inserted into the service, fleet, or sensitivity calculations. We retain the seven years for which the FS reports planning outputs: 2030, 2034, 2039, 2044, 2049, 2054, and 2059 (Korea Export-Import Bank, 2024).

The working dataset was assembled from the FS tables and operating assumptions needed to reproduce the service path. It contains maximum daily passenger-on-board (POB), the peak and off-peak POB components, demand-based and applied frequency/headway, passenger round-trip time (RTT), passenger-fleet requirement, baggage-train operation, internal route-conflict disruption, and additional vehicle procurement. The stated operating day is 19 h, or 1,140 min.

The FS assigns 240 min to peak service (two hours in the morning and two hours in the afternoon/evening) and 900 min to off-peak service. It does not state the corresponding clock times. We therefore do not introduce assumed windows such as 07:00-09:00 or 17:00-19:00.

Passenger service runs through all five stations; the baggage movement is limited to Ngurah Rai Airport-Central Park. The FS uses a 29-min passenger RTT. Its planning capacities are 271 passengers per trainset in the peak period and 194 off peak. We keep these inputs unchanged in the checks below. The resulting calculations test whether the FS quantities can be reproduced from its own assumptions. They are not presented as an economic optimum, a complete circulation model, or a stochastic timetable solution.

Table 2. Core longitudinal dataset for baseline and reproducibility checks

Year	Max daily POB	Peak POB/4h	Off-peak POB/15h	Demand freq.	Applied h	Applied freq.	Required fleet	Track disruption
2030	15,991	5,756	10,235	75	10	114	4	19.99%
2034	18,201	6,552	11,649	86	10	114	4	n.a.
2039	21,417	7,712	13,705	100	8	143	5	24.39%
2044	25,212	9,076	16,136	118	8	143	5	n.a.
2049	27,085	9,752	17,333	126	7	163	6	27.42%
2054	28,466	10,248	18,218	132	7	163	6	n.a.
2059	29,919	10,772	19,147	139	6	190	6	31.51%

Source: Korea Export-Import Bank (2024), Tables 7.6-26, 7.6-29 and 7.6-31 (pp. 7-83 to 7-86), fleet requirements (pp. 7-91 to 7-96), and internal route-conflict disruption rates (pp. 7-89 to 7-91). POB = passenger-on-board; h = headway in minutes; n.a. = the FS does not report a separate disruption value for that horizon.

2. Minimum demand-based service and applied-service indicators

We first reconstruct the passenger trips implied by the FS demand components. Peak and off-peak POB are divided by the corresponding planning capacities and then added to obtain daily demand-based frequency. The result is used as a capacity benchmark, not as a recommended timetable. This step is deliberately simple: if the calculation cannot reproduce the quantities implied by the FS, the later derived indicators would have little value.

$$F_{\text{peak},y} = D_{\text{peak},4h,y} / C_{\text{peak}} \quad (1)$$

where $F_{\text{peak},y}$ is the required peak trips in year y ; $D_{\text{peak},4h,y}$ is four-hour peak POB; and $C_{\text{peak}} = 271$ passengers/trainset.

$$F_{\text{off},y} = D_{\text{off},15h,y} / C_{\text{off}} \quad (2)$$

where $F_{\text{off},y}$ is the required off-peak trips; $D_{\text{off},15h,y}$ is 15-hour off-peak POB; and $C_{\text{off}} = 194$ passengers/trainset.

$$F_{\text{dem},y} = F_{\text{peak},y} + F_{\text{off},y} \quad (3)$$

where $F_{\text{dem},y}$ is the total daily demand-based frequency per direction.

Equation (4) compares the applied passenger frequency with the frequency obtained from the FS demand and capacity assumptions. The percentage difference is termed the service-intensity premium. It is used here only as a descriptive gap between two service quantities; the metric itself does not classify that gap as reserve, inefficiency, or an optimal margin.

$$P_y = [(F_{\text{app},y} - F_{\text{dem},y}) / F_{\text{dem},y}] \times 100\% \quad (4)$$

where P_y is the service-intensity premium; $F_{\text{app},y}$ is applied passenger frequency; and $F_{\text{dem},y}$ is the minimum demand-based frequency.

$$\text{TKM}_y = F_y \times L \quad (5)$$

For Eq. (5), daily frequency is multiplied by the 6.04-km mainline length. The result is commercial train-km per direction per day, used here to compare the amount of scheduled service across horizons. No conversion to operating cost or energy use is made.

Table 3. Demand-based minimum service and applied passenger service

Year	Demand freq.	Applied freq.	Extra trips	Premium	Demand train-km/dir.	Applied train-km/dir.
2030	75	114	39	52.0%	453.00	688.56
2034	86	114	28	32.6%	519.44	688.56
2039	100	143	43	43.0%	604.00	863.72
2044	118	143	25	21.2%	712.72	863.72
2049	126	163	37	29.4%	761.04	984.52
2054	132	163	31	23.5%	797.28	984.52
2059	139	190	51	36.7%	839.56	1,147.60

Source: Author calculations from FS demand-based and applied-frequency tables and the 6.04-km mainline length.

3. Fleet-transition verification and infrastructure-use indicators

Fleet requirement is checked independently of the demand calculation. The FS combines a 29-min passenger RTT, a 10% reserve principle, and train-diagram verification. For the arithmetic check used here, RTT is divided by the applied headway and the result is rounded upward to obtain active trainsets. One reserve passenger trainset is then added. This reproduces the FS requirement at each of the four headway states. The purpose is traceability; a full circulation analysis would require more detail.

$$N_{op,y} = \text{ceil}(\text{RTT} / h_{app,y}) \quad (6)$$

where $N_{op,y}$ is the active passenger trainsets; $\text{RTT} = 29$ min; and $h_{app,y}$ is applied passenger headway.

$$N_{req,y} = N_{op,y} + N_{res,y} \quad (7)$$

where $N_{req,y}$ is the total passenger-trainset requirement and $N_{res,y}$ is the reserve fleet. Across the analyzed horizons, the FS requirement is reproduced by adding one reserve passenger trainset to the active fleet.

Table 4. Independent fleet-formula verification against feasibility-study requirements

Applied headway	Active sets-formula	Active sets-FS	Reserve	Required-formula	Required-FS	Audit
10 min (2030/2034)	$\text{ceil}(29/10)=3$	3	1	4	4	Match
8 min (2039/2044)	$\text{ceil}(29/8)=4$	4	1	5	5	Match
7 min (2049/2054)	$\text{ceil}(29/7)=5$	5	1	6	6	Match
6 min (2059)	$\text{ceil}(29/6)=5$	5	1	6	6	Match

The calendar does not show by itself what demand level is associated with a service change. We therefore express each stage relative to maximum daily POB in 2030. The route-conflict disruption measure is treated in the same way by recording its change from the 2030 value. One FS term requires clarification. Its 'level crossing' refers here to an internal railroad-railroad conflict between passenger and baggage movements at Ngurah Rai Airport and Central Park, not to a road-rail grade crossing.

$$TR_s = \text{POB}_s / \text{POB}_{2030} \quad (8)$$

where TR_s is the POB transition ratio for stage s and POB_{2030} is the opening-year maximum daily POB.

$$\Delta DR_s = DR_s - DR_{2030} \quad (9)$$

where ΔDR_s is the increase in the FS internal route-conflict disruption rate relative to 2030.

4. Sensitivity and robustness analysis

The sensitivity test is deterministic. Each POB component is rescaled by 0.80, 0.90, 1.00, 1.10, and 1.20, corresponding to -20%, -10%, baseline, +10%, and +20% demand. The two bands are

intentionally bounded. The $\pm 10\%$ cases represent a moderate departure from the FS baseline, while $\pm 20\%$ provides a wider, material planning stress band that remains interpretable while the other FS operating assumptions are held unchanged. Together they form a transparent deterministic robustness envelope rather than an empirical confidence interval or a claim about the full volatility of Bali tourism. More extreme shocks, such as a pandemic, natural disaster, major flight-network change, or structural tourism disruption, could exceed $\pm 20\%$. However, changing only POB while keeping RTT, train capacity, the baggage timetable, reserve rule, and procurement lead time fixed would make such extreme cases increasingly artificial. Extreme-shock analysis is therefore better addressed in future work through multivariable scenarios or stochastic modelling. We do not assign probabilities to the five cases. They are used for two checks: whether the FS applied service would still meet the arithmetic demand requirement, and how much the dates of the later stages would shift if demand remained persistently below or above the baseline forecast.

$$S_{q,y} = (1 + q) \times POB_y \quad (10)$$

where $S_{q,y}$ is scenario demand in year y , q is the proportional deviation ($-0.20, -0.10, 0, +0.10, +0.20$), and POB_y is baseline FS demand.

Peak demand is used for the headway check because it is the binding period in the FS capacity calculation. We treat the baseline service as arithmetically sufficient when its headway is equal to or shorter than the scenario requirement. If a scenario requires a shorter headway, the next service stage needs review before the corresponding baseline FS year.

Stage timing is checked against the baseline POB thresholds for Stage II (8 min/5 sets), Stage III (7 min/6 sets), and Stage IV (6 min/system review). For a given demand scenario, the crossing year is interpolated between the two adjacent FS horizons that contain the threshold. If the scenario has not reached a threshold by 2059, the result remains outside the study period. No demand trajectory is projected beyond the final FS horizon.

$$Y_{s,q} = Y_i + [(POB_s - S_{q,i}) / (S_{q,i+1} - S_{q,i})] \times (Y_{i+1} - Y_i) \quad (11)$$

where $Y_{s,q}$ is the estimated trigger-crossing year for stage s under scenario q , and $S_{q,i}$ and $S_{q,i+1}$ are scenario demands at the bracketing FS horizons. Equation (11) assumes that demand changes locally in a linear manner between the two adjacent FS horizons used to bracket a threshold. It therefore cannot represent nonlinear growth, abrupt shocks, seasonality, or structural changes that occur between those points. The estimated crossing year should consequently be read as an approximate planning indicator, not a precise forecast date.

Some quantities in the analysis are taken directly from the FS and others are calculated from those values. Table 5 keeps the distinction visible by showing, for each analytical item, the FS location, the equation or table used in the reanalysis, and the planning output that follows.

Table 5. Numerical traceability of FS inputs and derived quantities

Analytical element	FS source location / derivation	Equation / table	Output / use
Passenger demand and service input	FS pp. 7-83 to 7-86; Tables 7.6-26, 7.6-29, 7.6-31	Table 2; Eq. (1)-(3)	Baseline demand frequency and headway
Applied passenger service	FS Table 7.6-31, pp. 7-85 to 7-86	Tables 2-3	Applied headway and frequency
Service-intensity premium	Derived from FS demand and applied frequencies	Eq. (4); Table 3	Service-policy diagnostic, not formal reserve
Train-km proxy	6.04-km mainline x frequency	Eq. (5); Table 3	Operating-intensity proxy, not cost/energy
Passenger fleet verification	FS passenger RTT and fleet requirement, pp. 7-91 to 7-96	Eq. (6)-(7); Table 4	Independent fleet cross-check

Analytical element	FS source location / derivation	Equation / table	Output / use
Transition and route-conflict indicators	FS POB values; route-conflict disruption, pp. 7-89 to 7-91	Eq. (8)-(9); Table 6	Service, asset, and system triggers
Additional vehicle procurement	FS O&M, p. 8-16	Analytical results	Independent check: +1 set in 2039 and +1 set in 2049
Demand sensitivity	FS POB x -20%, -10%, 0, +10%, +20%	Eq. (10); Table 7	Peak-headway robustness
Transition timing robustness	Baseline trigger POB + linear interpolation	Eq. (11); Table 8	Scenario timing envelope

Note: Values taken from the FS are distinguished from quantities calculated in this paper. The demand cases are deterministic; baseline calculations use no external numerical dataset.

Before using the derived measures, we checked two parts of the arithmetic against values already reported in the FS. Equations (1)-(3) recover its demand-frequency sequence. Equations (6)-(7) recover the passenger-fleet count at all four headway states and place the added sets in 2039 and 2049, matching the O&M schedule. These are consistency checks on our reconstruction, not evidence that the FS demand forecast will occur.

Analytical Results

The demand series and the service plan behave differently. Maximum daily POB increases at every horizon, from 15,991 in 2030 to 29,919 in 2059, while applied headway changes only in 2039, 2049, and 2059. Reconstructed frequency likewise rises from 75 to 139 trips per direction. For RQ1, the operational path is therefore four states rather than seven separate plans: 10 min, 8 min, 7 min, and 6 min.

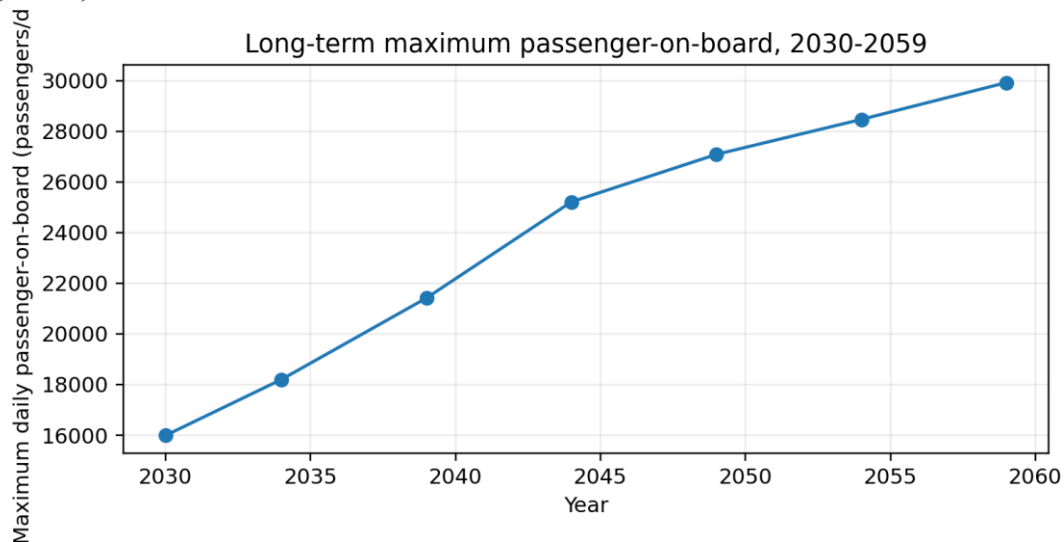


Figure 1. Long-term maximum daily passenger-on-board, 2030-2059

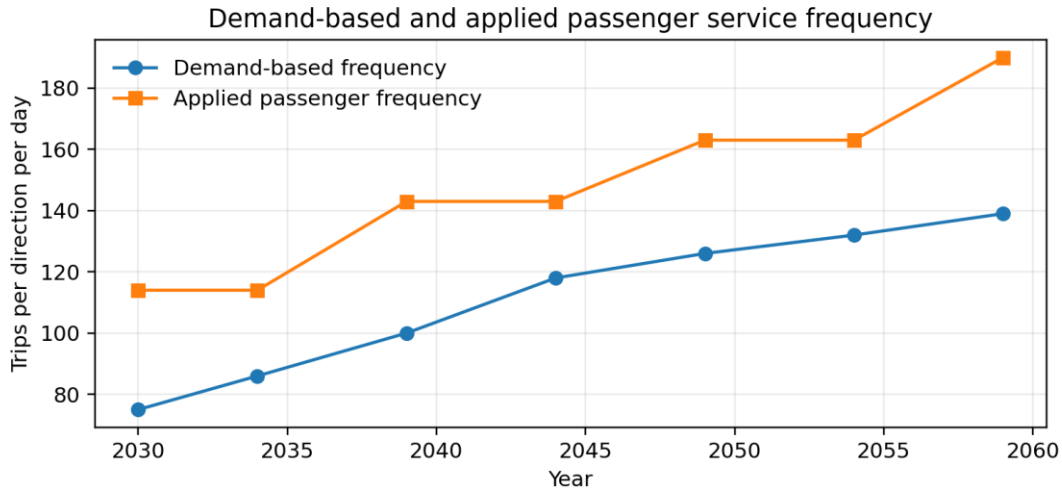


Figure 2. Demand-based and applied passenger service frequency

The three later service changes occur at maximum daily POB ratios of 1.339, 1.694, and 1.871 relative to 2030. A fleet increase accompanies the first two changes: four passenger trainsets become five at 8 min and six at 7 min. The third change behaves differently. At a 6-min headway, $\text{ceil}(29/6)$ still gives five active sets, so one reserve keeps the total requirement at six. The FS O&M schedule independently places one additional trainset in 2039 and another in 2049, each costed at USD 5.6 million. Thus RQ2 separates two service-and-fleet transitions from a final service-only transition.

Table 6. Baseline service, fleet, and infrastructure/system transition stages

Stage	Year	h (min)	Max POB	POB ratio	F_dem	F ratio	Req. sets	DR (%)	ΔDR (pp)
I	2030	10	15,991	1.000	75	1.000	4	19.99	0.00
II	2039	8	21,417	1.339	100	1.333	5	24.39	+4.40
III	2049	7	27,085	1.694	126	1.680	6	27.42	+7.43
IV	2059	6	29,919	1.871	139	1.853	6	31.51	+11.52

At every baseline horizon, applied service remains above the reconstructed demand minimum. The difference ranges from 21.2% to 52.0%, while applied train-km per direction grows from 688.56 to 1,147.60 train-km/day. These numbers describe the distance between a capacity-only minimum and the FS service plan. They are not performance scores. The FS does not provide an objective function combining waiting time, operating cost, reliability, airport connectivity, energy, and passenger willingness to pay, so the premium cannot establish efficiency or optimality on its own.

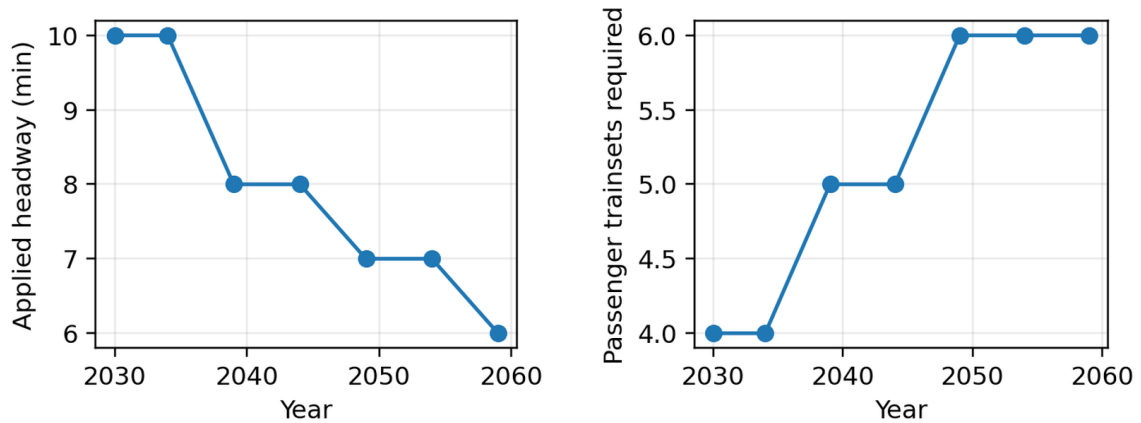


Figure 3. Service and fleet transition stages for Bali LRT Phase 1A, 2030-2059

The route-conflict values provide a different signal from fleet size. At the two passenger-baggage conflict locations, the FS reports 19.99% at 10 min, 24.39% at 8 min, 27.42% at 7 min, and 31.51% at 6 min. The FS also states that the tested operation does not create a train-operation problem. We therefore do not read these percentages as failure probabilities or proof of line saturation. For RQ3, their value is that they show increasing interaction as service becomes denser and provide a reason to review the system separately from the service and fleet triggers.

Table 7. Sensitivity of demand-based peak headway to forecast deviation

Year	Applied h FS	-20%	-10%	Baseline	+10%	+20%
2030	10	15	12	11	10	10
2034	10	12	11	10	9	8
2039	8	11	10	9	8	7
2044	8	9	8	8	7	6
2049	7	9	8	7	6	6
2054	7	8	7	7	6	6
2059	6	8	7	6	6	5

Note: Scenario values are demand-based peak headways in minutes. A scenario value shorter than the baseline applied headway indicates that the baseline service would need earlier review.

Table 8. Robustness envelope for service, fleet, and system-review transition timing

Scenario	Multiplier	Stage II: 8 min/5 sets	Stage III: 7 min/6 sets	Stage IV: 6 min/system review	Interpretation
-20%	0.80	~2048.2	Not reached by 2059	Not reached by 2059	Strong delay
-10%	0.90	~2042.1	Not reached by 2059	Not reached by 2059	Delay
Baseline	1.00	2039	2049	2059	FS calendar
+10%	1.10	~2036.0	~2043.2	~2049.4	Accelerated
+20%	1.20	~2033.4	~2040.5	~2043.6	Strong acceleration

Table 8 shows an imbalance between upside and downside demand error. At +10%, the three later thresholds are reached at about 2036, 2043, and 2049; at +20%, about 2033, 2041, and 2044. Lower demand delays rather than reverses the sequence: Stage II moves to roughly 2042 (-10%) or 2048 (-20%), and Stages III and IV are not reached by 2059. The 2034 headway check points in the same direction, with about 9 min under +10% demand and 8 min under +20%, compared with the 10-min baseline. For RQ4, the practical issue is the lead time available before the next service or fleet decision must be prepared.

Discussion

1. Why the 6-min state is different

The fleet arithmetic makes the final transition unlike the earlier two. At 8 min, $\text{ceil}(29/8)=4$ active sets and one reserve gives five; at 7 min, $\text{ceil}(29/7)=5$ plus one reserve gives six. Tightening again to 6 min does not add another set because $\text{ceil}(29/6)$ is still five. Applied service nevertheless rises to 190 trips per direction per day. Under the FS assumptions, the 2059 step is therefore a service-intensity decision rather than another rolling-stock procurement point.

2. Demand thresholds as a second planning reference

The POB ratios detach the transition logic from exact calendar years. Stages II, III, and IV correspond to 1.339, 1.694, and 1.871 times the 2030 maximum daily POB. Because the Phase 1A alignment is fixed, this is not the same problem as staging new links or stations (Wu & Schonfeld, 2022) or choosing the size and timing of a new rail investment (Guo et al., 2023). The question here is when an existing corridor should be worked more intensively and which resource - service, fleet, or route capacity - needs attention next.

3. Interpreting the service-intensity premium

Table 3 shows that the FS schedules more passenger trips than the reconstructed seat-capacity minimum at every horizon; the gap ranges from 21.2% to 52.0%. We use the term service-intensity premium only to keep track of that difference. Because applied frequency remains above the capacity-only minimum, this gap can function as an operational service cushion against ordinary day-to-day variation in airport passenger volume: some short-term increase in demand can be absorbed before an immediate move to the next service stage is required, while the higher frequency can also help limit waiting time within the airport-access chain. This interpretation is deliberately cautious. The premium is not a formal spare-capacity reserve, a quantified reliability margin, or proof of efficiency, because the FS does not provide the daily demand distribution, a reliability model, or an objective function combining waiting time, transfers, operating cost, energy, airport connectivity, and willingness to pay. On an airport link, the gap is therefore best read as a service-policy buffer with potential operational value, not as a measured reserve (Wang et al., 2022; Avogadro et al., 2024).

4. Route interaction at the final fleet state

Fleet size alone does not describe the final stage. The FS route-conflict indicator rises from 19.99% at the 10-min state to 31.51% at 6 min, although the tested operation is still reported as feasible. We treat that increase as a prompt for a more detailed timetable check, not as a failure probability. Route occupation, terminal turnback, signaling, dwell variation, maintenance allocation, and recovery margin would need to be tested before denser operation is adopted.

5. What demand error changes

The sensitivity results change the amount of warning available before a decision. Under +20% demand, the two fleet-related transitions move from the baseline years 2039 and 2049 to about 2033 and 2041; under +10%, to about 2036 and 2043. Lower demand pushes the same decisions later. This supports using the FS years as scheduled review points rather than automatic activation dates: the sequence survives the tested demand range, but the calendar attached to it does not.

That interpretation is limited to the stress test used here. Only POB is scaled; RTT, train capacity, the reserve rule, baggage timetable, and procurement lead time are held fixed. The test does not represent tourism shocks, mode substitution, flight-schedule changes, day-to-day variability, or correlated uncertainty. In this paper, 'structure robust' therefore means only that the order of service-fleet-system decisions is unchanged within the $\pm 20\%$ demand cases, while

'timing sensitive' means that the crossing years move. Operational control would require richer timetable and uncertainty analysis.

6. Use in planning and limits of transfer

For an operator, the required follow-up depends on the threshold being approached. Near a service-only transition, the immediate work is to test timetable performance and route use. Near the 8- or 7-min states, the same review must also include rolling-stock procurement and its lead time. The +20% case illustrates the consequence: the two fleet-related thresholds move from 2039 and 2049 to about 2033 and 2041. The FS calendar can still support governance and budgeting, but the operating decision should be reopened when the evidence approaches the relevant demand threshold.

The procedure is transferable; the numerical thresholds are not. Another project would have to supply its own demand horizons, train capacity, RTT/headway policy, reserve rule, and interaction measure. The Bali results remain bounded by a single FS forecast, deterministic +/- 10% and +/-20% cases, and interpolated crossing years. Once the line opens, observed demand and timetable evidence should replace those planning assumptions wherever possible.

Conclusion

The reanalysis changes the use of the FS calendar, not the underlying FS numbers. Seven forecast horizons resolve into four operating states - 10, 8, 7, and 6 min - while passenger fleet requirement follows 4, 5, 6, and 6 trainsets. The 6-min state is the important exception to a simple 'more service means more trains' rule: with a 29-min RTT, five active sets plus one reserve remain sufficient, while the passenger-baggage route-conflict indicator reaches 31.51%, shifting attention from another trainset purchase to how the existing fleet and shared route are used. Demand provides a second reference for timing: relative to 2030, the later states occur at 1.339, 1.694, and 1.871 times maximum daily POB, and their crossing years move to about 2036/2043/2049 under +10% demand and 2033/2041/2044 under +20%, while lower-demand cases are delayed. The practical implication is to retain the FS years for budgeting and scheduled review rather than treat them as fixed activation dates, and to decide on each next operating state using observed demand, current service adequacy, fleet readiness, and passenger-baggage interaction.

Bibliography

- Avogadro, N., Birolini, S., Redondi, R., & Deforza, P. (2024). Assessing airport ground access interventions: An integrated approach combining mode choice modeling and microscopic traffic simulation. *Transport Policy*, 148, 154-167. <https://doi.org/10.1016/j.tranpol.2024.01.013>
- Bandara Internasional I Gusti Ngurah Rai. (2026, January 12). Bandara I Gusti Ngurah Rai layani 24,1 juta penumpang sepanjang 2025. In *Journey Airports*.
- Guo, Q., Chen, S., Sun, Y., & Schonfeld, P. (2023). Investment timing and length choice for a rail transit line under demand uncertainty. *Transportation Research Part B: Methodological*, 175, 102800. <https://doi.org/10.1016/j.trb.2023.102800>
- He, J., & Li, Y. (2024). Research on airport express train schedule optimization based on demand-driven air-rail intermodal transportation. *Scientific Reports*, 14, 28473. <https://doi.org/10.1038/s41598-024-77067-5>
- Hrušovský, M., Hemmelmayr, V., Schett, G., Birkmaier, A., & Schlund, S. (2025). Integrated planning approach for fleet sizing and fleet management of freight railcars. *Flexible Services and Manufacturing Journal*, 37, 869-903. <https://doi.org/10.1007/s10696-024-09556-8>

- Kementerian Perhubungan Republik Indonesia. (2024, January 10). Bertemu Wamen Transportasi Korsel, Menhub bahas upaya penyelesaian feasibility study dan pembiayaan LRT Bali. Kementerian Perhubungan Republik Indonesia.
- Korea Export-Import Bank. (2024). Feasibility study for the Bali LRT construction project 1A section: Final report. Korea Export-Import Bank.
- Liu, J., Canca, D., & Lv, H. (2023). Spatiotemporal synchronous coupling algorithm for urban rail transit timetables design under dynamic passenger demand. *Applied Mathematical Modelling*, 119, 239-256. <https://doi.org/10.1016/j.apm.2023.02.016>
- Nampu, R. (2024, January 9). Korlantas Polri evaluasi kemacetan jalur menuju Bandara Ngurah Rai. ANTARA.
- Setiawan, D., Priyanto, S., Amrozi, M. R. F., & Muthohar, I. (2025). The comparison of main features and minimum service standards of air-rail integrated services (ARIS) implementation in Indonesia. *Multimodal Transportation*, 4(3), 100224. <https://doi.org/10.1016/j.multra.2025.100224>
- Wang, P., Xiao, X., & Nießen, N. (2024). Flexible rolling stock composition strategy in urban rail transit lines: The influences of various train units and station capacities. *Transportation Research Part C: Emerging Technologies*, 162, 104609. <https://doi.org/10.1016/j.trc.2024.104609>
- Wang, Z.-J., Jia, H.-H., Dai, F., & Diao, M. (2022). Understanding the ground access and airport choice behavior of air passengers using transit payment transaction data. *Transport Policy*, 127, 179-190. <https://doi.org/10.1016/j.tranpol.2022.09.001>
- Wu, F., & Schonfeld, P. (2022). Optimized two-directional phased development of a rail transit line. *Transportation Research Part B: Methodological*, 155, 424-447. <https://doi.org/10.1016/j.trb.2021.12.007>
- Zhao, Y., Li, D., Yin, Y., & Zhao, X. (2023). Integrated optimization of demand-driven timetable, train formation plan and rolling stock circulation with variable running times and dwell times. *Transportation Research Part E: Logistics and Transportation Review*, 171, 103035. <https://doi.org/10.1016/j.tre.2023.103035>
- Zhuo, S., Miao, J., Meng, L., Yang, L., & Shang, P. (2024). Demand-driven integrated train timetabling and rolling stock scheduling on urban rail transit line. *Transportmetrica A: Transport Science*, 20(3), 2181024. <https://doi.org/10.1080/23249935.2023.2181024>