New Southern Sky (NSS)

Airport Collaborative Decision Making (A-CDM) Benefits, Metrics and Enablers

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Disclaimer

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Glossary

A-CDM	Airport Collaborative Decision Making
ADOC	Aircraft direct operating cost
ALDT	Actual time of landing
AIBT	Actual in-blocks time
AOBT	Actual off-blocks time
ASAT	Actual start approval time
ASRT	Actual start request time
ATC	Air traffic control
ATOT	Actual time of take-off
CPDSP	Collaborative pre-departure sequencing process
CTA	Controlled time of arrival
CTOT	Calculated time of take-off
ELDT	Estimated landing time
EOBT	Estimated off blocks time
IMC	Instrument meteorological conditions
TOBT	Target off blocks time
TSAT	Target start approval time
TTOT	Target time of take-off

Executive Summary

This report sets out to bring clarity to what benefits might be achieved in New Zealand by Airport Collaborative Decision Making (A-CDM). The primary purpose of A-CDM is to improve efficiency, punctuality and the predictability of air traffic, in particular during the turn-round process at an airport.

A-CDM has been put in place in Auckland and Wellington, however ongoing evolution in the environment: increasing traffic in Auckland, and ongoing civil works in Wellington have masked the impact of A-CDM and challenged the ability to distinguish results.

This study aims to identify the benefits of A-CDM, the enablers and challenges to realising those benefits, and define metrics to measure the results.

From data on approximately 770,000 movements, the study found that

- 15% to 20% of departures encounter some level of surface movement congestion
- The cost of delays during taxiing is, at a rough order of magnitude estimate, in the region of \$1.4M to \$6.8M. Delays include waiting with engines running, and also lengthened block time and the impact of late or off schedule operations.

A-CDM enables the gate agent involved in aircraft turn-round to forewarn air traffic control about the target off blocks time (TOBT), enabling the controller to better plan the use of the runway and airfield. A-CDM also enables the controller to manage the timing of flights by issuing a target start approval time (TSAT) such that delays can be taken (if available) at the gate stand at lower cost.

The data shows that taxi delays are reduced when surface movement traffic density is held below a critical threshold. The controller would use the A-CDM process to ensure that surface movement traffic remained free flowing.

This study identified metrics to measure the effect of A-CDM on taxi delays in and out of the gate stands, runway efficiency, airborne delays on approach, and the balance between these effects. The metrics are able to distinguish infrastructure change from tactical operations, allowing the benefits of each to be captured. In addition, the metrics monitor total block delay for the flights, revealing the impact of congestion on airline schedules. In the long run, it is envisaged that this information would allow well informed discussions about the cost and benefit of capital projects related to capacity improvement.

There are challenges to overcome in order to realise the A-CDM pre-departure sequencing process. These include ensuring that TOBT is supplied and is trustworthy, that predicted arrival times for inbound flights are also sufficiently accurate to be useful on the required timescales, and that the process itself is agreed, tested, and followed, including making sure that TSAT is available to all who would use it.

Stakeholders could consider a staged course of action to realise the benefits of A-CDM. The first objective could reduce taxi-out delays using short term planning and existing TOBT data quality. A second stage could realise improved approach efficiency, use of runway and stand capacity, and on time performance after an investment in improving the quality of arrival and departure demand estimates on a longer time horizon (70-90 minutes).

1 Introduction

Airport collaborative decision making (A-CDM) is a process in which key actors in the aviation system share data in real time and use it to improve the results of their operations. It aims in particular to optimise the airport turnaround process by predicting near term future aircraft movements more accurately for airlines, airports, gate agents, and air traffic control. In turn it is believed that A-CDM, when used effectively, can improve the use of airport and airline assets and avoid costs related to delays during operations.

It is “collaborative” in the sense that the originator of the data, the beneficiary of the improved outcomes and the actor who enables the improvements to happen may be different stakeholders. For example, in the case of an aircraft transiting through an airport, the gate agent may rely on the arrival time predicted by air traffic control to organise handling the aircraft at the gate, however the benefit of good performance in this regard could be an increased probability of the aircraft being on time at its next destination.

The foundations of A-CDM have been put in place at Auckland and Wellington Airports, and other locations are considering whether to proceed with A-CDM implementation. Both they and the New Southern Sky (NSS) programme of the Civil Aviation Authority of New Zealand are interested to inform their management decisions by quantifying the benefits of A-CDM, and identifying the enablers that would lead to realising those benefits.

This report sets out to bring clarity to what benefits might be achieved by A-CDM in New Zealand and what metrics and enablers would help realise those benefits.

The task is challenging because of the inherent complexity of the aviation system. Air transport is delivered by multiple stakeholders acting autonomously to varying degrees, and generally with visibility only into a subset of the whole of the system. The outcome for each actor can be affected by factors outside their control – for example, the actions of others creating congestion where resources are limited (such as airport gates, runways, and airspace capacity), or external factors such as weather.

This complexity means that the improvements arising from any systematic change can be difficult to predict, or such change may not deliver the expected result. In particular, optimising a part of the overall process (say, the part under the control of one stakeholder) may produce a sub-optimal or ineffective result depending on the relationship of that particular change to the system as a whole. Although A-CDM may enable individual actors to alter their operations, whether a net benefit can be realised requires clarity about the system-level effect of any change.

To bring clarity to A-CDM, the analysis in this report takes a whole-of-system view, and models the functions of A-CDM in context. The models have been refined using interviews with the delivery experts from the various stakeholders in New Zealand, and comprehensive data from Auckland and Wellington installations.

The remainder of this report covers:

- The background to A-CDM and the current NZ installation
- The outcome to date and the challenges and opportunities identified by airports
- The potential feasible benefits of A-CDM in the NZ context
- Enablers that could help realise the benefits
- Metrics suited to the NZ context: outcome measurements, lead indicators for process improvement, and data quality verification.

2 A-CDM

2.1 A-CDM background

The New Zealand A-CDM implementation described in the *A-CDM Concept of Operations* [1], adapted from generic concepts originating in Europe. The document is closely based on the Australian equivalent [2] which derives in turn from original work in Europe by Eurocontrol and partners [3] [4].

The primary aim of A-CDM is to improve efficiency, punctuality, and predictability of air traffic, with a focus on the turnaround process for aircraft arriving and then departing from an airport. The founding concept is that the various stakeholders involved can improve decision making and the allocation of shared resources, such as runways and gate stands, if they have a shared situational awareness based on sufficiently accurate and timely predictions about future aircraft movements.

A-CDM enables these improvements in two ways. After defining a common framework of operational milestones around the airport turnaround process, A-CDM implements a method for the stakeholders to exchange the relevant data both for predicting and for managing the demand.

The A-CDM concept implies that the relevant processes involve decisions based on this shared information, have formalised procedures with an effective means of managing change, and have a method of monitoring the process performance to ensure that improvements can be sustained[1].

2.2 A-CDM in New Zealand

A-CDM technology was established in Auckland in June 2015, and in Wellington in April 2016. The technical system comprises:

- software components in the airport operational system,
- a defined set of data transfer between the airports and air traffic control,
- portals on the airport operating system for use by ground handling coordinators during aircraft turnaround
- Interactive items on the control tower electronic flight strips for use by controllers

Figure 1 A-CDM Ground Handler's Web Portal

[1] [4], p 2-9

Ongoing change at both Airports has confounded the ability to clearly identify changes in performance as a result of A-CDM. Auckland airport has had continuous growth in traffic, causing a net rise in taxi delays despite process quality improvement. Wellington airport has deployed a sequence of developments and alterations to the manoeuvring area after which average taxi times have reduced but the contribution of A-CDM to that reduction is unclear.

The A-CDM implementation relies on manual data entry in several ways. In particular, the target off blocks time (TOBT) must be entered and updated by the gate handling agent. The gate agent's role has a significant workload during aircraft turn-round, with the result that TOBT and other manual entry data has not been entered at times. The airports have primarily focussed their attention to date on improving the participation rate by stakeholders tasked with data entry, with some success.

This study aims to identify the benefits that could be addressed by the current A-CDM installation, identify the enablers and challenges to realising those benefits and propose metrics to measure the results.

3 Overview of A-CDM

As context for capturing benefits from A-CDM, this chapter briefly describes the information exchanged between A-CDM partners, and the operational factors of interest to stakeholders that A-CDM enabled decisions could positively influence. Details of A-CDM will be familiar to many readers, however they are included here for context and completeness, and also with a structure that clarifies the later discussion of benefits and appropriate metrics.

3.1 New Information delivered by A-CDM

In New Zealand, A-CDM exchanges information between airports and air traffic control, providing each with new information previously only held by the other. The data include not only status updates to maintain a common situational awareness as events occur, but also schedule and planning information to enable collaborative traffic management processes [5].

3.1.1 Current Flight Status

Airport and air traffic control exchange actual times of on-blocks and off-blocks, take-off and landing, and flight plan state. This data enables all parties to maintain a common situational awareness of the state of each flight, and can be used to estimate the timing of future events and for measuring outcomes.

Airport	Direction	ATC
	⇦	actual take off time at origin airport for arrivals
	⇦	actual local landing time for arrivals
	⇦	Actual local take off time for departures
	⇦	Flight state (filed, airborne, landed, cancelled)
Actual in blocks time for arrivals	⇨	
Actual off blocks time for departures	⇨	

Table 1 A-CDM Flight Status Data

3.1.2 Planning Information

Also exchanged are predicted landing time for arrivals, target off blocks time for departures, and runway and stand assignments. These data enable prediction of demand for the runway and stands, including the variable taxi time required depending on the surface movement route between runway and stand.

Airport	Direction	ATC
	⇦	Estimated off blocks time (from flight plan)
	⇦	**Estimated landing time (ELDT)** for arrivals
	⇦	Allocated runway at origin and destination
Allocated Stand	⇨	
Target Off Blocks Time (TOBT) for departures	⇨	

Table 2 A-CDM Planning Information

Of these data the estimated landing time (ELDT) and target off blocks time (TOBT) are commonly considered the most important of the A-CDM data set as a whole, because they advise all downstream processes. A prerequisite for success is that TOBT and ELDT are sufficiently timely and accurate to serve the processes that rely on them.

3.1.3 Schedule Information

A-CDM exchanges schedule information with air traffic control. Prior to A-CDM, air traffic control had no flight schedule information. Although as yet unused, this information creates the potential for the air traffic flow management (ATFM) process to prioritise traffic in line with schedule needs and participate in improving on time performance. For each airport turn-round, airport A-CDM sends the timing expectations in the form of the scheduled arrival time and target off blocks time for the subsequent departure for both anticipated arriving flights and anticipated departure flights.

Airport	Direction	ATC
Departure: scheduled in blocks time of prior arriving flight	→	
Departure: target off blocks time (TOBT) as above		
Arrival: scheduled in blocks time		
Arrival: Target off blocks time (TOBT) of subsequent departure		

Table 3 A-CDM Schedule Information

The timing information for linked flights is important information which potentially enables new services: prioritising flights to improve on time performance, and managing flights with tight turn times to maintain schedule. Prior to A-CDM, no schedule or stand pressure information was available to air traffic flow control. This data also supports schedule-based service improvements.

3.1.4 Demand management information

The final group of data exchanged is intended to control the flow of aircraft. Target start approval time (TSAT) controls the pushback and start of departures at an airport, while controlled time of take-off (CTOT) originates with ATFM and is intended to time the take-off of a flight for best effect at its eventual destination airport.

Airport	Direction	ATC
	←	Target start approval time (TSAT)
		Controlled time of take-off (CTOT)

Table 4 A-CDM Demand Management Information

3.2 Value opportunities for A-CDM

The A-CDM operations concept highlights reducing taxi time and delays and improving on time performance as prime objectives. This section reviews the value attached to these issues.

3.2.1 The scale of taxi delay

Most flights are not delayed during taxiing however the cost of taxi delays suggest that a business case could be made for a project aimed at reducing avoidable delays. Figure 2 shows the proportion of traffic delayed during taxi at each airport, in 5-minute bands. Most traffic is delayed less than 5 minutes (the limit of precision for the available data), and few flights incur delays greater than 10 minutes[2].

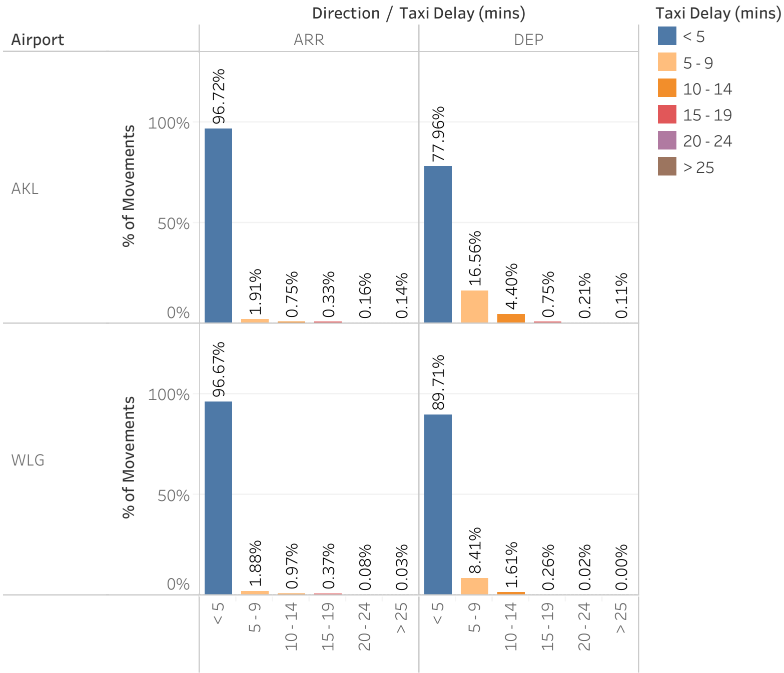

Figure 2 Proportion of Traffic Delayed During Taxi

The following charts show data for a sample year in which detailed data is available for both airports. The period selected is exactly 52 weeks to avoid bias created by the variation in daily traffic volume on different days of the week. After distinguishing between wide body and narrow body international jets, domestic jet and regional turboprop traffic, regional turboprop movements predominate at both airports.

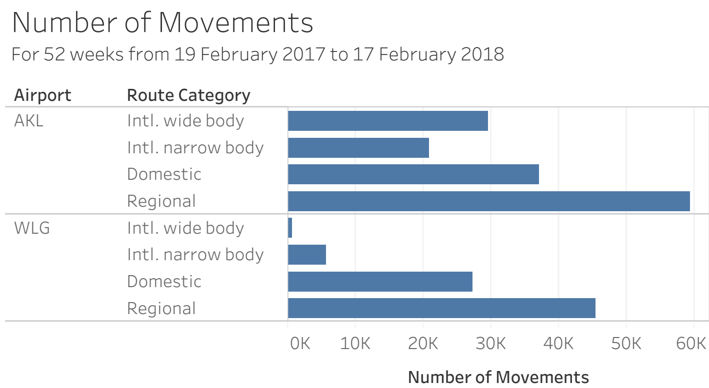

Figure 3 Volume of Traffic by Aircraft and Route Category

[2] The analysis excludes very long taxi times, on the basis that higher taxi times are rare and more likely to result from unforeseen one-off events rather than from the traffic management process. The estimates should also be treated as "indicative" rather than "definitive" as the data have timing precision limitations, for which we use statistical methods to reduce noise in the results. More detailed description of the calculations is discussed in Appendix C.

Regional turboprop flights are not only most frequent but also encounter taxi delays more often and to a greater degree.

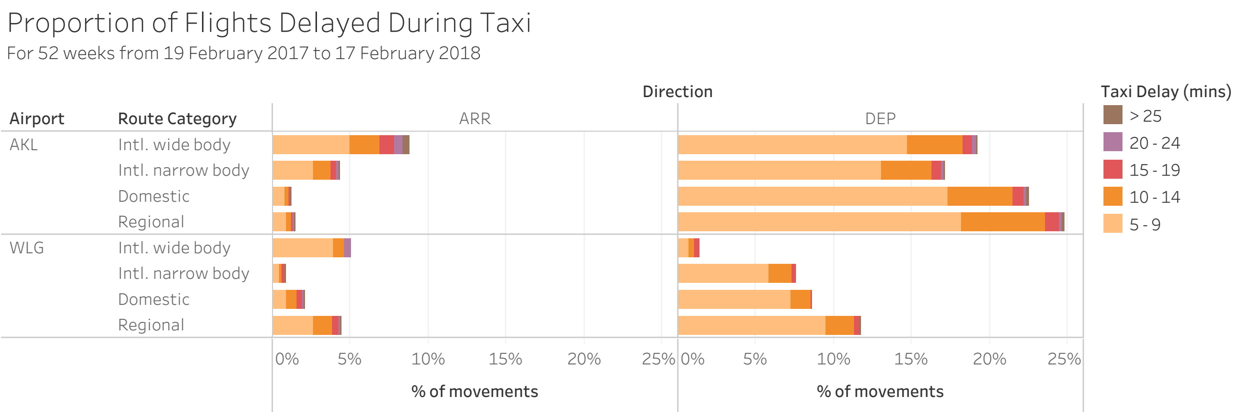

Figure 4 Proportion of Traffic Category Delayed During Taxi

As a result, at both airports, the bulk of departure delays are incurred by regional traffic. Arrival taxi delays in Auckland are predominantly for international arrivals, in Wellington for regional arrivals.

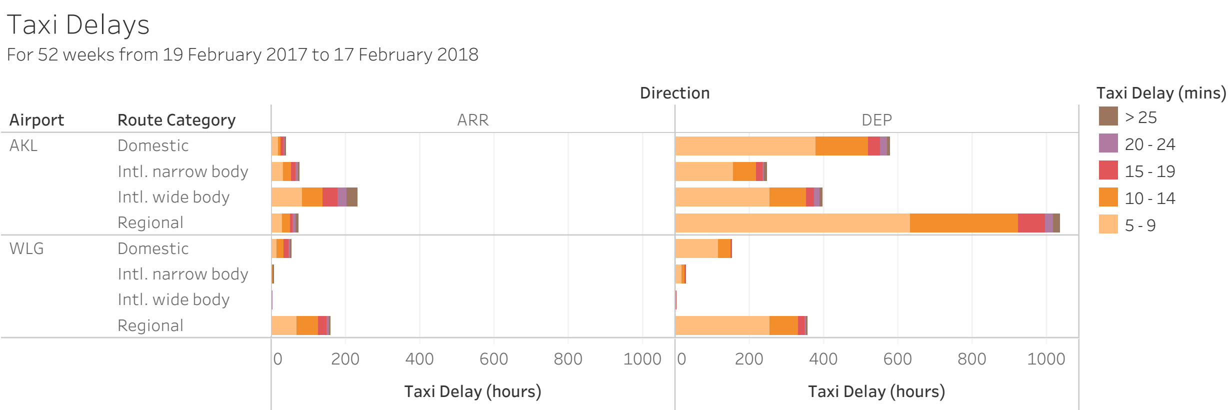

Figure 5 Taxi Delay in Hours by Route Category

The data does not contain aircraft type information however, for illustration, an approximate estimate can be made of the cost of the taxi delay waste. Using the marginal direct operating costs typical of aircraft in each route category, the indicative cost of taxi delay is shown in Table 5, rounded to two significant figures in acknowledgement of the limitations of precision in the data. International traffic is partitioned into narrow and wide body types, based on the aircraft operator and routes flown. Air New Zealand, Jetstar, Virgin Australia and some Qantas flights between New Zealand and eastern Australia or the closer Pacific islands are presumed to be narrow body jets, as are any flights by those operators with both domestic and international legs. Aircraft with international inbound or outbound legs further afield, or operated by other carriers are presumed to be wide body. Aircraft with inbound or outbound legs to regional locations within New Zealand are presumed to be turboprop types. The method for estimating these figures is contained in Appendix C, and uses the marginal direct operating costs of taxi time for aircraft typical of the route category. Given the above assumptions and approximations, to the extent that an A-CDM process may reduce wasted taxi time, these figures illustrate the scale of potential gains.

Cost of taxi delay for 52 weeks from 19 February 2017 to 17 February 2018

Airport	*Direction*	*Delay*	*Intl. wide body*	*Intl. narrow body*	*Domestic*	*Regional*	*Total*
Auckland	Arrival	>15	280,000	39,000	31,000	18,000	368,000
		10 - 14	260,000	65,000	28,000	26,000	379,000
		5-9	420,000	100,000	51,000	37,000	608,000
		Subtotal	**960,000**	**204,000**	**110,000**	**81,000**	**1,355,000**
	Departure	>15	100,000	31,000	76,000	48,000	255,000
		10 - 14	480,000	190,000	440,000	370,000	1,480,000
		5-9	1,300,000	480,000	1,200,000	800,000	3,780,000
		Subtotal	**1,880,000**	**701,000**	**1,716,000**	**1,218,000**	**5,515,000**
Airport	*Direction*	*Delay*	*Intl. wide body*	*Intl. narrow body*	*Domestic*	*Regional*	*Total*
Wellington	Arrival	>15	1,600	6,100	54,000	44,000	105,700
		10 - 14	2,200	3,300	59,000	71,000	135,500
		5-9	5,400	4,300	44,000	88,000	141,700
		Subtotal	**9,200**	**13,700**	**157,000**	**203,000**	**382,900**
	Departure	>15	1,200	5,700	17,000	28,000	51,900
		10 - 14	820	23,000	97,000	98,000	218,820
		5-9	1,100	58,000	350,000	320,000	729,100
		Subtotal	**3,120**	**86,700**	**464,000**	**446,000**	**999,820**

Table 5 Indicative Aircraft Direct Operating Cost of Taxi Delay ($NZ)

3.2.2 Value of on time performance

Late running of flights creates additional tactical costs on the day of operation. There are immediate costs of re-accommodating passengers who have missed connections with onward flights, and reactionary delays created by the disruption to the aircraft and crew's forward schedule, possibly for several aircraft rotations if the schedule has little slack available to absorb delays over the subsequent rotations. Delays may also propagate to other aircraft needing airport stands occupied by late running flights.

These costs have a non-linear relationship with the aircraft lateness. Passenger itineraries typically allow some slack time for making connections at airports, and accommodate a small amount of delay to the inbound flight. Once the connection buffer is exhausted, passenger costs of lateness rise. European research found that the costs of lateness rise in a power law, with per minute costs of delay at 60 minutes of delay approximately four times those at 15 minutes of delay, and costs at 3 hours of delay approximately double those at 1 hour[3].

If lateness propagates to the last flight of a crew's duty roster, airline costs can rise significantly. Air New Zealand particularly notice this effect on the last outward flight of the day to regional locations. Although a crew may have sufficient available duty time to crew the evening outbound flight, rest requirements may prevent that crew operating the same aircraft on time for the first flight of the next day. The airline options include flying a fresh crew in the afternoon to the regional location in order to operate the next day's first flight, effectively costing from ½ to a full day's additional crew time to service the flight schedule. Alternatively, flights may be cancelled, creating passenger costs and aircraft and crew repositioning costs – the equivalent of an additional non-revenue flight in addition to passenger care expenses.

For airlines, reducing the risks of late running incurs long term strategic costs in the form of additional schedule buffers needed to recover schedule between aircraft rotations, and the additional fleet and crew capacity required by these buffers [6]. Aircraft waiting at airport stands during this buffer add to the stand capacity required and therefore the airport capital costs. This is a longer-term trade-off judgement for airlines when creating feasible schedules, balancing tactical delay and the cost of buffers, and is

[3] [6] page 5

affected primarily by the average block time (the elapsed time from off blocks at origin to on-blocks at destination) expected for flights between each airport pair. Metrics capturing the benefits of A-CDM therefore need to measure A-CDM contribution to reducing block time, and improving on time arrival.

The costs tend to be specific to the circumstances of each flight. Schedule buffer, passenger connections, and crew duty limits differ by flight. Extensive analysis of the costs of delay in Europe, while delivering standard cost tables, emphasises that the indicated costs are recommended for the purpose of giving insight, and not for specific analysis due to the variability of these contributing factors[4]. This study does not attempt to quantify these costs in detail, however the scale of these costs can be indicated for illustration.

In this analysis, we distinguish between the costs of delays and the cost of lateness. The delay costs have been discussed earlier as immediate tactical direct operating costs of the aircraft and crew when waiting for runway or stand access. Here, we discuss the distinct costs associated with lateness from schedule. The lateness costs are treated as "at stand", and incurred on late delivery of travelling passengers for each late running flight.

European costs are thoroughly detailed in the "European airline delay cost reference values" study [7]. The extensive European study for the Performance Review Unit of Eurocontrol found that the hard costs of lateness are dominated by the outlay for passenger care[5]. The passenger costs are treated as zero for the first 15 minutes of delay, owing to the buffers built into passenger itineraries and expectations. Beyond that, costs rise in a 'power law' in which the per-minute cost rises in proportion as the total delay increases. Hard passenger costs vary over a 2:1 range from low to high scenarios, with baseline (middle) scenarios of EU 0.24/passenger-minute for 30-minute delay, EU 0.56/passenger minute for 90-minute delays, and Eu0.96/passenger-minute for 180-minute delays.

As a convenient simplification, Air New Zealand use nominal constant figures of NZD 0.12/passenger-minute for regional operations, NZD 0.16/passenger-minute for domestic jet operations, and NZD 0.32/passenger-minute for international operations.

Purely for illustration, Table 6 shows the rough order of magnitude cost of lateness (more than 15 minutes after scheduled arrival time) at 80% load factors for aircraft typical of regional, domestic jet, and international operations, using Air New Zealand's figures for the hard costs of passenger care. Actual costs of lateness are likely to be greater, especially beyond 30 minutes of lateness, after which disruption cost of aircraft and crew re-assignment begin to emerge.

Route Category	Example Aircraft Capacity	Cost of Lateness > 15 minutes (rough order of magnitude)
Regional	ATR72, 68 seats	$6.50/minute
Domestic Jet	A320, 171 Seats	$21/minute
International	B777-300, 342 Seats	$87/minute

Table 6 Indicative cost of lateness

3.2.3 The robustness of on time performance

Air New Zealand, as is common, target 85% of flights to arrive no later than 15 minutes after the scheduled time at destination. In practice, at both Auckland and Wellington, this is close to actuality for most operators. Figure 6 shows the spread of departure and arrival times relative to schedule, and the cumulative total of movements across the time line. All categories of flight (international, main trunk, and regional) achieve very close to the common industry target of 85% of movements no later than 15 minutes after scheduled time.

[4] [13] page 8
[5] [13] page 8

In the long term, on time performance as traditionally defined tends to be constant. Airlines target on-time performance, and compensate for systematic changes in the air traffic system by amending schedules so that flights are likely to be considered on time. Consistent changes in block time lead to schedule adjustments. It follows that efforts to improve on time performance at a system level will not appear in the standard on time performance target, due to changes being absorbed into the airline schedules.

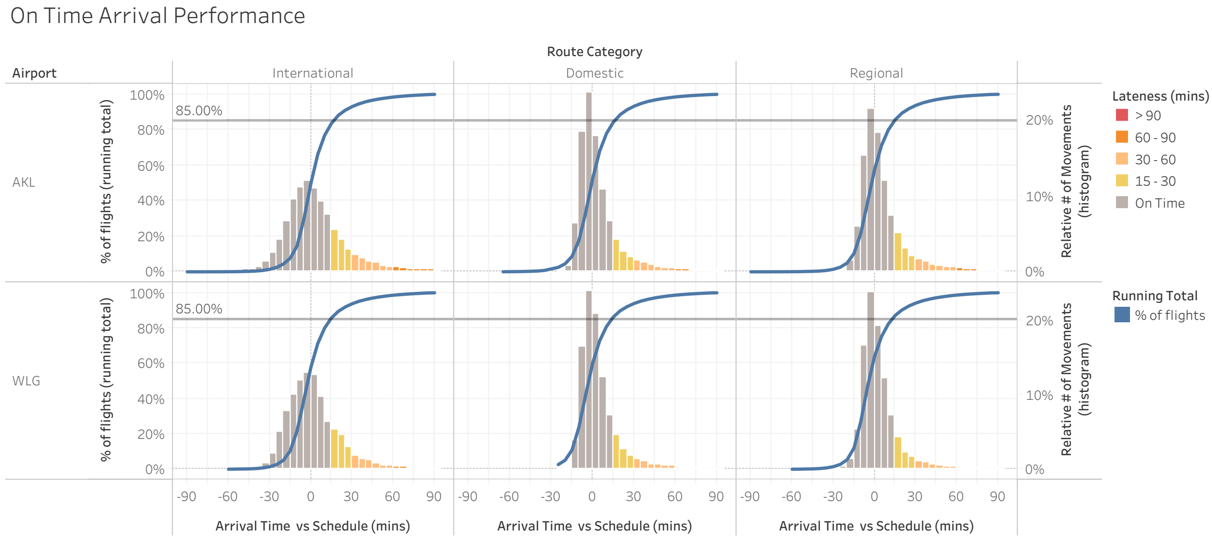

Figure 6 Spread of On Time Performance

Accepting, for the moment, that the 85th percentile will be fixed at 15 minutes late in the long term, reducing the cost of lateness will require reducing the spread of arrival time relative to schedule. Existing scheduling practice means 15% of flights would still be more than 15 minutes late, however the number of flights later than 30 minutes would reduce. To achieve cost of lateness reductions, A-CDM processes would need to reduce the variability of flight arrival times.

The impact of system wide changes to delays in the long run are absorbed by the airline schedule in this way, however the gain or loss is measured in the change in block time. Therefore, proposed metrics in this study capture the total delay imposed on a flight as it works its way through the infrastructure. Longer term changes in this total delay figure illustrate benefits of infrastructure change.

4 A-CDM Processes

4.1 The collaborative pre-departure sequencing process (CPDSP)

The collaborative pre-departure sequencing process coordinates off-block planning between all stakeholders. It is predicated on departure demand indicated by the target off blocks time (TOBT).

TOBT represents the best estimate of the gate handling agent or aircraft operator of the time at which the flight will be ready to start and move.

CPDSP envisages an off-blocks planning process in which a planner:

- plans an efficient departure sequence in the conditions, considering the arrival and departure traffic demand, and assigns the target time of take-off (TTOT) for the flight
- computes the target start approval time (TSAT) required for the flight to make the TTOT, taking into account the variable taxi time required depending on the route between stand and runway
- communicates TSAT to all stakeholders via the A-CDM platforms.

Ideally, the process controls the flow of aircraft from gate stand to runway, preferably to meet the departure CTOT window, in an optimum sequence that maximises runway capacity utilisation and that does not compromise arriving flights[6]. TSAT then becomes the indicator of future airfield movements for all other stakeholders. It should inform the flight crew of the start time, air traffic control of departure demand, and the stand allocation function of the stand availability.

The expected results of CPDSP include:

- Reduced taxi out time
- Optimised runway utilisation
- The departure is aligned with flow control, takes off within any allocated CTOT window so that the flight time is also optimised
- On time arrivals.

4.1.1 Reducing Taxi Out Time

By working back from the TTOT, TSAT will ensure an efficient taxi out. If a start delay is required, it will automatically be taken on the stand. TSAT time-shifts the aircraft taxiing so that it arrives at the runway close to the planned take off time (Figure 7). The wait time shifts from engines running on the taxiway (a), to engines off at the stand (b) saving fuel and reducing emissions and aircraft direct operating costs.

[6] Whilst the current intention in New Zealand is to have an ATC role in the control tower perform the CPDSP process, it is notable that CPDSP need not necessarily be performed by air traffic control. For example, during runway works at San Francisco in 2014 Robinson Aviation operated a Departure Metering Coordination Centre to enable the airport and airline operators to collaboratively self-manage push back and start, metering departures using the DMAN feature of the SAAB Aerobahn product [17]. A similar system is in use at New York JFK. The flow of departures from the ramp was well enough ordered that the ordinary first-come, first-served ATC process achieved a satisfactory outcome [20].

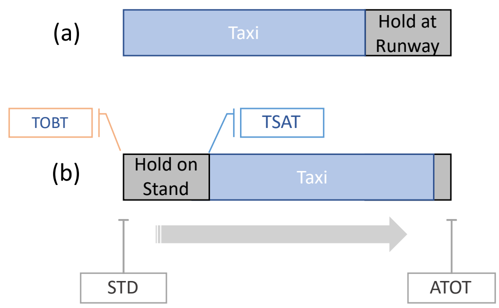

Figure 7 Hold on Stand Enabled by TSAT

Shifting the locale of the delay does not necessarily reduce the delay experienced by the flight. This delay, due to congestion at the runway, creates a late running risk, and increases block time for the flight.

To capture a rounded picture of the net effect of A-CDM, the proposed metrics measure both the taxi time saving and the net delay.

4.1.2 Optimising Flight Time

For flights to Auckland, Wellington, Christchurch, and Queenstown, the air traffic flow management process (ATFM) assigns an arrival time at the destination to balance runway demand with capacity. Working back to the take-off time using the estimated elapsed flight time, the departure is assigned a matching controlled time of take-off (CTOT).

If a delay is required, departing at CTOT will move any delay from airborne holding time (a) to ground holding at the origin airport (b) (Figure 8), reducing the cost but not the size of the delay.

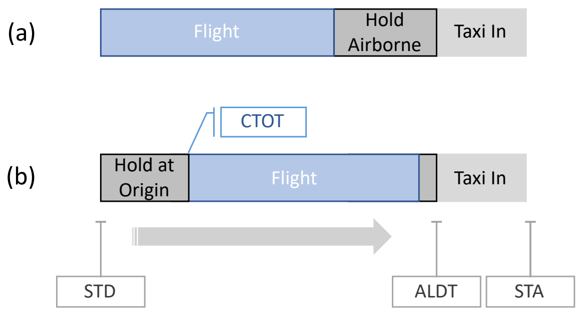

Figure 8 Ground Holding Delay Enabled by CTOT

Again, to capture a holistic picture of the effect on the flight, metrics measure both the airborne delay savings, and the net delay to the flight block time.

4.1.3 Optimising Runway Utilisation

As a system, the runway merges arrivals and departures two independent, yet interacting, flows of air traffic. Both form queues for the runway.

In this system, A-CDM indicates demand for each queue in the form of estimated landing time (ELDT) for arrivals and target off blocks time (TOBT) for departures.

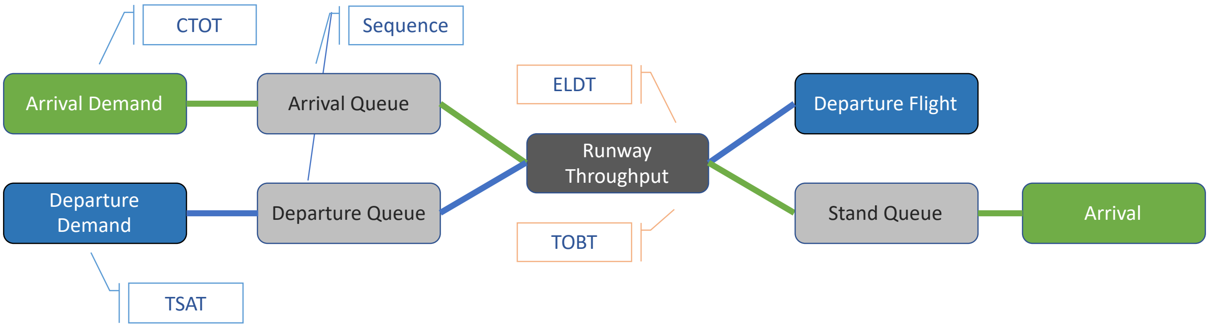

Figure 9 Airport Centric View of Traffic Flows with A-CDM Enabled Controls

Functionally, for the runway system:

- Estimated landing time (ELDT) indicates arrival demand, and TOBT indicates departure demand
- CTOT and TSAT moderate the flow of traffic to the runway using ground holding at origin for arrivals and holding on the stand for departures.
- The resulting moderated flow of traffic forms the demand for the runway.
- The output from the runway is ideally the whole of the demand, limited only by the runway capacity.
- The arrival and departure streams are delayed when the runway is unable to completely absorb the demand.
- The arrival and departure queues fill (creating airborne and taxi out delays) when the flow controls (CTOT and TSAT) do not completely compensate the delays.

Because both CTOT and TSAT together moderate the entire flow across the runway, there is a risk of over-compensating for anticipated holding delays and reducing the flow rate below the runway capacity. Whilst this could substantially remove holding delays, it would add overall delay to the flight, increasing the flight's block time.

The overall system must balance between several objectives

- Minimise airborne holding on approach for arrivals
- Minimise taxi delays for departures
- Optimise runway throughput
- Enable departures to meet any applicable CTOT window, to the benefit of flight efficiency at the destination
- Enable arrivals to meet scheduled arrival time.
- Enable departures to meet scheduled arrival time at destination

To capture the net effect of the runway system, metrics need to include runway capacity utilisation and on time performance.

4.1.4 Stand Availability

Both CTOT and TSAT affect taxi in delays. CTOT (at the origin airport) affects the timing of arrivals, which must wait to access the assigned stand if it is occupied at the time they arrive. TSAT affects the departure of the preceding flight and therefore the stand availability.

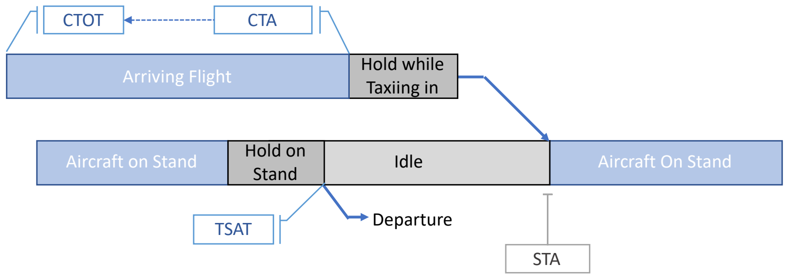

Figure 10 Arrival Delay Affected by TSAT and CTOT

The ability of a departure to hold on the stand, rather than incur taxi delay, depends on the available idle time before the arrival of the next flight assigned to the stand. There is therefore a trade-off between arrival and departure taxi delay for stands with short idle times. This means that maximising the available idle time is one of the key objectives for optimising stand assignment to flights. Average minimum idle time would be a lead indicator for the stand allocation process.

Where insufficient idle time is available there is a balance to be struck between taxi in and taxi out delay, or the departure may need to be sequenced earlier in the departure queue.

Furthermore, early arrivals either conflict with the prior departing flight or reduce the available idle time. There is therefore an advantage when arrivals land closer to scheduled arrival time.

To optimise stand allocation and therefore realise on time performance and block time benefits, the planning horizon needs to extend beyond the duration of the inbound flight. Maximising stand idle time requires the estimated landing time (ELDT) for not only the immediate next flight but also the subsequent one, in other words - good enough estimates for landing are needed one flight cycle ahead.

Metrics to capture the impact of A-CDM on stand availability include taxi in time, and the proportion of flights delayed waiting for stands.

4.2 Metrics

The metrics proposed in this section are lag indicators intended to capture the results of the combined A-CDM and ATFM processes. The metrics capture the time and cost of delays that incur direct aircraft operating costs, and also the block time delay that creates tactical late running risk as well as increasing the fleet and operating costs for airlines in the strategic timescale. The metrics also capture capacity efficiency related to runways and gate stands, enabling stakeholders to objectively consider the role of capacity constraints on block delays.

Although the purpose of this study - to identify metrics able to capture the value of A-CDM - precludes studying how to improve the various processes in detail, some lead indicators are noted during the analysis. It is envisaged that stakeholders who are intent on realising the potential of A-CDM would continue on to study the system constraints where results are currently suboptimal, and develop process improvement plans which include objective lead indicator KPIs.

4.2.1 Taxi Out Delay

Taxi and block delays can be directly measured and costed.

Metric	Measure	Notes
Taxi Delay	Actual Taxi Time – Reference Taxi Time	Measures the difference between actual and unimpeded taxi time.
Block Delay	Taxi Delay + Start Delay	Measures the delay to the flight due to congestion and traffic management
Delay Cost	Taxi Delay x ADOC (Taxiing) + Start Delay x ADOC (Engines off)	Measures the aircraft direct operating cost (ADOC) of delay to the flight
Delayed Flights	% of flights experiencing block delay	Measures the proportion of flights that are delayed by congestion

Table 7 Taxi Out Delay Metrics

The reference taxi time represents the unimpeded taxi time that would occur absent any cause of delay. The reference taxi time is measured empirically from historical data, taking into account any relevant factors. For the reference time in the taxi delays in this paper we have used the median taxi time for aircraft on the applicable stand-runway route when traffic flow and traffic density are low, thus removing the most significant causes of delay. Auckland airport also take into account the aircraft type and operator when deriving this unimpeded taxi time. Several methods exist for the statistical derivation; a method using linear regression is described in [8].

The reference taxi time is the baseline for this metric, and should be revised on any occasion where surface movement routes are changed. The revision in the baseline would then capture the gains or losses due to the changed surface movement infrastructure, and the taxi out delay metric would continue to capture operational performance independently of the influence of the infrastructure change

When computing individual flight delays the reference time for each flight is the moment the flight is ready to move, denoted by the actual start request. At this time the aircraft should be ready to move with doors closed, tug in place, and airbridge clear.

Supporting metrics	Actual taxi time	= ATOT – AOBT
	Taxi Delay	= AOBT – ASRT
	Start Delay	= ASAT – ASRT

4.2.2 Approach Delay

Approach holding delays can also be directly measured and costed. Approach delay is measured by comparing the time actually taken by the aircraft, including any track extension due to holding or radar vectoring as required to merge the flight into the approach sequence, with the time required to fly the shortest applicable approach procedure.

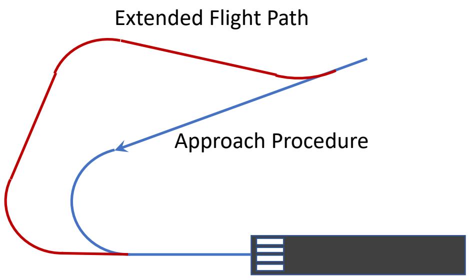

Figure 11 Approach Delay Extended Flight Path

Metric	Measure	Notes
Approach Delay	Actual Approach Time – Reference Approach Time	Measures the difference between actual and unimpeded approach time.
Approach Delay Cost	Approach Delay x ADOC (Cruise)	Measures the aircraft direct operating cost (ADOC) of the airborne delay
Delayed Flights	% of flights experiencing approach delay	Measures the proportion of flights that are delayed by congestion

Table 8 Approach Delay Metrics

Where

- Actual approach time is the elapsed time between the time of first crossing 100nm from the airfield to the time of crossing the runway threshold.
- Reference approach time is the length of the instrument procedure from a point 100nm from the destination airfield, divided by the average speed actually flown by the aircraft.
- The reference instrument procedure is the shortest applicable IFR procedure available to the flight, using the pair of runways actually used at the departure and destination airports.

This method was used in previous work analysing the benefits of the New Southern Sky PBN implementation [9]. The 100nm range from destination represents a standard arrival and sequencing area (ASMA), and is known to capture all of the airspace used for route extension in current ATS practice in New Zealand. The 100nm range for the ASMA is also used by the FAA and Eurocontrol for capturing flight efficiency during the arrival/descent phase of flight [10]. For flights from airports within 100nm, an area around the point of departure should be excluded, to remove the influence of any procedure variations at the departure airport.

Selecting the reference instrument procedure on the basis of the runway pair used by the flight enables this metric to isolate the tactical operational delay from the effects of duty runway selection. This is particularly helpful for the short flight routes from nearby airports (Woodbourne, Nelson) where the entire flight is composed of departure and arrival procedures that vary significantly depending on duty runway selection at each airport.

The reference instrument procedure path length represents the baseline for this metric. The reference path for each runway pair can be captured statistically from historical data, usually as the route normally taken in moderate or low traffic periods during IMC.

This reference path length should be revised whenever a change is made to the navigation infrastructure. The change in reference path length would then capture the benefits due to the navigation change, whilst the airborne delay metric would continue to capture the tactical operational results from the A-CDM and ATFM traffic management processes.

4.2.3 Runway Utilisation

Runway utilisation compares actual delivery with demand, limited by runway capacity. It is a qualitative metric indicating whether the block delays that occur are the result of over demand or under delivery. For credibility, the runway capacity used as a reference is derived empirically from historical data, as a demonstrated throughput that has been achieved in practice.

Metric	Measure	Notes
Runway Efficiency	Actual Flow Rate / Feasible Flow Rate	Measures actual delivery compared to demand, or to capacity if demand exceeds capacity.

Table 9 Runway Utilisation Metrics

Where

- Actual Flow Rate is the average inter-movement time for flights in a rolling 30-minute window prior to each movement
- Feasible Flow Rate is the lesser of actual demand or demonstrated runway capacity under the circumstances.
- Actual demand is the flow rate that would occur if aircraft arrived at the runway unimpeded (as though the runway had unlimited capacity). It is measured as for actual flow rate as the average inter-movement time over a 30-minute rolling window prior to each delayed flight, but using the unimpeded runway time for each movement. The unimpeded runway time is derived for each movement by subtracting the queue delay if any from the actual runway time:
    - For arrivals, unimpeded runway time = ALDT - Approach Delay
    - For departures, unimpeded runway time = ATOT - Taxi Out Delay
- Demonstrated runway capacity is variable, determined empirically, and selected on the circumstances affecting the flight including the effect of weather conditions and the arrival/departure ratio on the runway capacity. Appendix B describes the factors relevant to establishing the runway capacity table for this metric.

Average inter-movement time is the average of the time between aircraft on the runway for a selected time window. This report uses 30 minutes preceding each flight. The results do not appear to be particularly sensitive to the length time window selected, except that excessively short windows will introduce sampling artefacts to the data, and long windows will mask short term peaks in traffic that create delays. The objective is to use a representative indicator of both runway pressure and runway delivery in a time scale that is material to the growth or decay of delay queues. Note that counting aircraft over fixed time periods does not serve the purpose of the metrics, as peaks that fall across time segment boundaries will not appear in the statistics. All flow rates should be measured using this inter-movement period technique, and preferably be expressed in units of movements/hour for familiarity with consumers.

4.2.4 Gate Stand Availability

Taxi in delays are measured, and flights holding for gates identified separately

Metric	Measure	Notes
Taxi In Delay, Taxi In Delay Costs	As for Taxi-out delay	
Block Delay	Equals Taxi Delay	Delay to the block to block time for the flight
Delayed flights	% of arrivals delayed during taxi	
Flights Delayed Due to Stand Availability	% of arrivals waiting for stand	An arrival is included if ALDT<AOBT of previous flight at the same stand

Table 10 Stand Availability Metrics

4.2.5 Capturing the value of A-CDM

The change over time of the average taxi out delay, average block delay, the average runway efficiency for delayed flights, the cost of delay, and the proportion of flights delayed indicates the value of the A-CDM process.

In the normal course of events, the delays can be expected to increase in line with increasing traffic levels, despite the gains made by an improved process.

To capture process improvements despite the change in traffic levels, the data can be partitioned by flow rate, so that like flow rates are compared between periods. The roll-up metrics can then capture the change at each level of congestion, with results indicating process improvement independently of the rising traffic levels.

Figure 12 shows the average taxi delay for a range of flow rates for Auckland and Wellington. The data indicate that delays in Auckland have been rising at quite low flow rates, and the year on year taxi delays at Wellington have been falling at most flow rates.

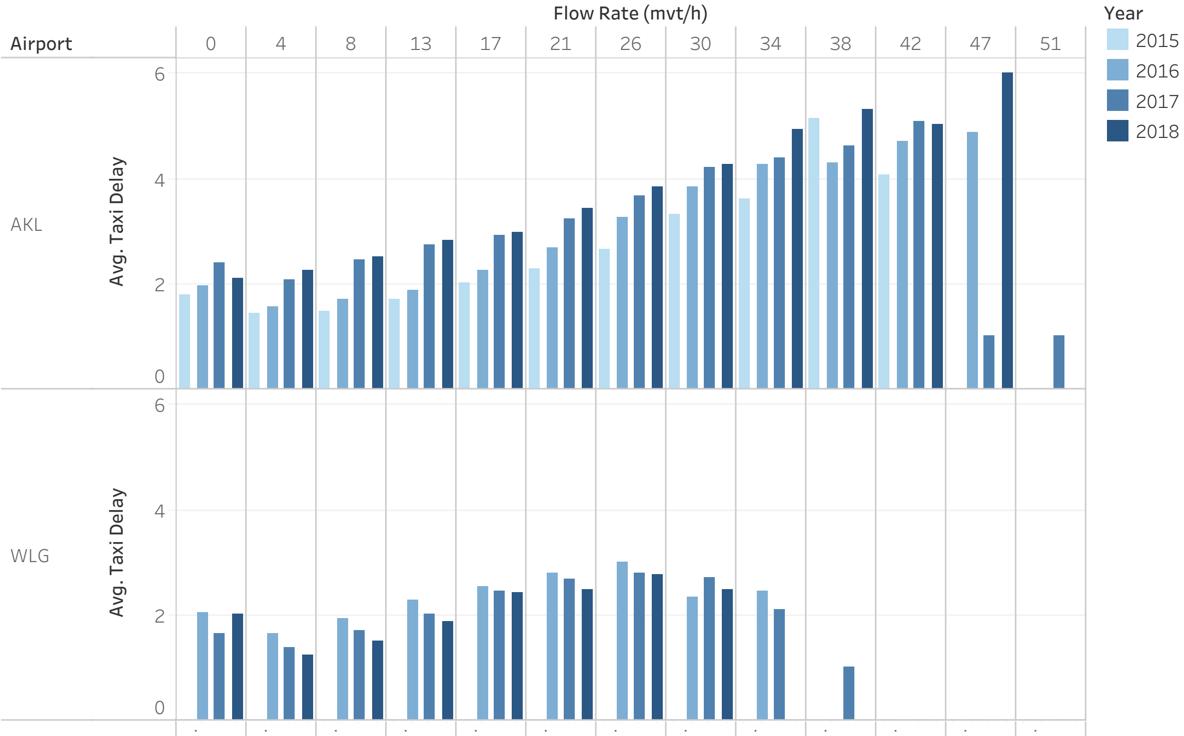

Figure 12 Taxi Delay vs Flow Rate for a range of dates

4.3 Implementation Challenges

4.3.1 Process Definition

Although the pre-departure sequencing process is outlined in the concept of operations it has not been put into practice in control tower procedures. Both Wellington and Auckland towers sequence departures on a first come, first served basis and manage by exception, leaving TSAT set to TOBT unless the airfield becomes too busy.

Controllers use the TOBT predominantly for immediate tactical planning. Controllers in both Wellington and Auckland explained that knowing when flights are about to become ready for push back is frequently used when deciding how to route taxiing aircraft, for example how far from a stand to stop an inbound flight in order to make room for the push back.

4.3.2 Controller Trust in TOBT

TOBT appears along with the control for TSAT on electronic flight strips in the control tower. Controllers have an expectation that the TOBT will be updated prior to issuing TSAT, and tend to distrust TOBT that have been entered well before that time and not changed subsequently.

In practice, TOBT often need not change and can be entered early. Flights with sufficiently long contact time at the stand, and with adequately resourced turn-round crew would be expected to be ready on time. TOBT for these flights could be entered at any time once it was clear that the flight is likely to run to schedule and TOBT would not be expected to change.

4.3.3 Fragility of the Boarding Process

Despite the preference by the tower departure planner for TOBT to be correct and stable 10 minutes prior to pushback, the turn-round process can experience failures quite late in the process. For example, the failure of a passenger to board, by definition, will occur at the end of the process, and trigger a delay while the missing passenger's baggage is offloaded and the remaining luggage re-stowed in the aircraft. The delay can be more than 20 minutes, and arise within minutes of the originally planned pushback time. The CPDSP decision making process would need to flexibly accommodate late disruptions.

4.3.4 TOBT Data Entry

TOBT is the responsibility of the gate agent handling the aircraft turn-round, and is manually entered. The intention is to enter a TOBT value once the feasible target off blocks time is known, and update it as required during the turn-round process to keep other stakeholders informed.

However, the turn-round process is a high workload task for the turn-round coordinator assigned to the flight. All turn-coordinators visited during this research were very busy during the aircraft turn-round; exceptionally so for the coordinators of regional flights. As a result, data entry tends to be triaged away, with the TOBT either not entered, or not updated sufficiently before the start request time for the departure controller to adequately plan the departure.

Both airports have focussed on progressively obtaining consistent TOBT entry from all turn-round handling agencies with improving but not yet complete coverage. The data shows TOBT being entered for between 65% and 96% of flights.

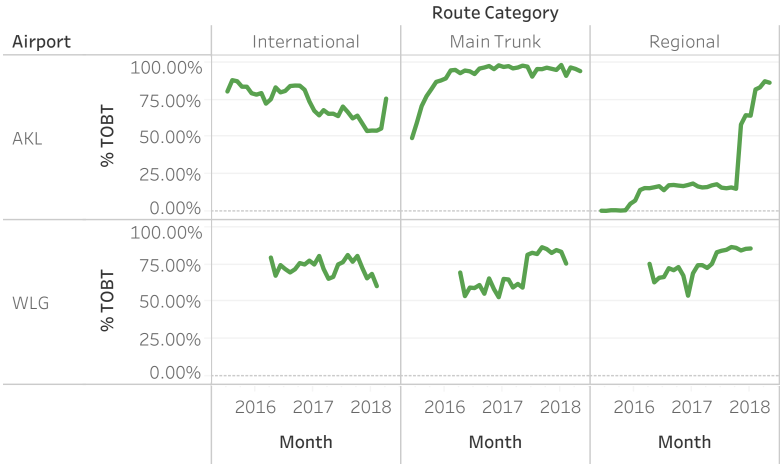

Figure 13 Proportion of departures with TOBT entered

4.3.5 TOBT Precision and Accuracy

Comparing TOBT with the actual start request times indicates that TOBT accuracy is good, however there is a relatively broad spread between start request time and TOBT that controllers have commented on. Calls for start several minutes after TOBT can be interpreted to mean that TOBT is not being maintained. TSAT and TOBT are not readily available to the turn-round or flight crews so that the process free runs with start called when the aircraft is ready. Having TOBT and TSAT readily available may align turn-round and start request activities more closely. The spread of ASRT relative to TOBT is a lead indicator for the quality of the flight's interaction with the A-CDM processes.

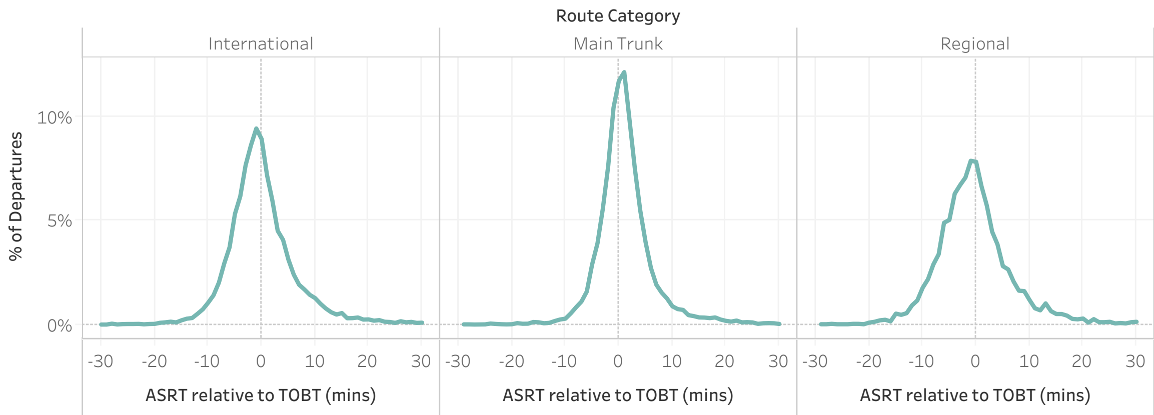

Figure 15 Spread of Start Request Time compared with TOBT (Auckland)

Both Wellington and Auckland airports are considering adding TOBT and TSAT to the nose in guidance systems for display to the flight crew, as part of aligning all of the turn-round preparations. Amsterdam Schiphol have also put in place an internet portal available to the public (https://mobile.ehamcdm.nl), which allows any stakeholder to access live data, using a mobile device if required, simply by entering the IATA flight ID.

As an indicator of practical levels of precision, London Heathrow require a report that the flight is ready to push at TOBT +/-5 minutes.

Figure 14 Schiphol A-CDM Web Portal

4.3.6 Integration with ATFM

Departure sequencing is determined tactically in the short term in conjunction with the approach control unit. Unless otherwise arranged, the approach unit will maximise the arrival rate with minimum spacing between arriving aircraft. Once aware of an imminent departure stream the tower and approach unit coordinate to space arrivals at a pace called for by the tower, in order to leave gaps for departures. The departures are then merged into the runway flow tactically by the tower controller.

The short-term tactical process can be suboptimal for flight efficiency. Inbound flights already airborne at the time the arrival spacing is increased can no longer be delayed on the ground prior to departure using CTOT but must be delayed in the air. For departure flights TTOT may not be aligned with a CTOT originating from flow planning at the destination, creating a goal conflict between meeting TSAT or conforming with the flight's assigned CTOT window.

Ideally, local A-CDM decision making and the network level ATFM would be harmonised. Doing so implies that departure planning (TOBT) is carried out in advance of the departure by at least the flight duration of arrivals landing at the departure time and is communicated to the ATFM arrival rate and assigned arrival time decisions so that arrivals end up spaced to accommodate departures without sacrificing flight efficiency.

4.3.7 ELDT Accuracy and Stability

Predicted landing times for arriving flights have relatively large errors and variability. The A-CDM concept of operations calls for estimated landing time (ELDT) at ETA – 70 minutes to be +/- 5 minutes for 98% of flights[7]. The current processes do not meet this requirement.

Figure 16 plots each received landing time estimate contained in the data set (there may be a sequence of estimates received over time for any one flight). The vertical scale shows the estimation error: the difference between the estimated landing time and the actual landing time eventually achieved. The horizontal scale shows the time at which the estimate is made, relative to the actual take off time at the origin airport.

Estimation errors are large, spanning more than +/- one hour for many flights, and reduce once a flight becomes airborne. Colour on the chart shows the on-time performance of the flight, with hotter colours indicating increasing lateness. Prior to departure, late running flights are often predicted to arrive earlier than they actually do, in other words, they are not predicted to be late. For many, the errors are proportional to the lateness, suggesting that the flights are simply predicted to be on time, with the prediction process insufficiently aware of the impending late running.

[7] [1] table 5, page 17

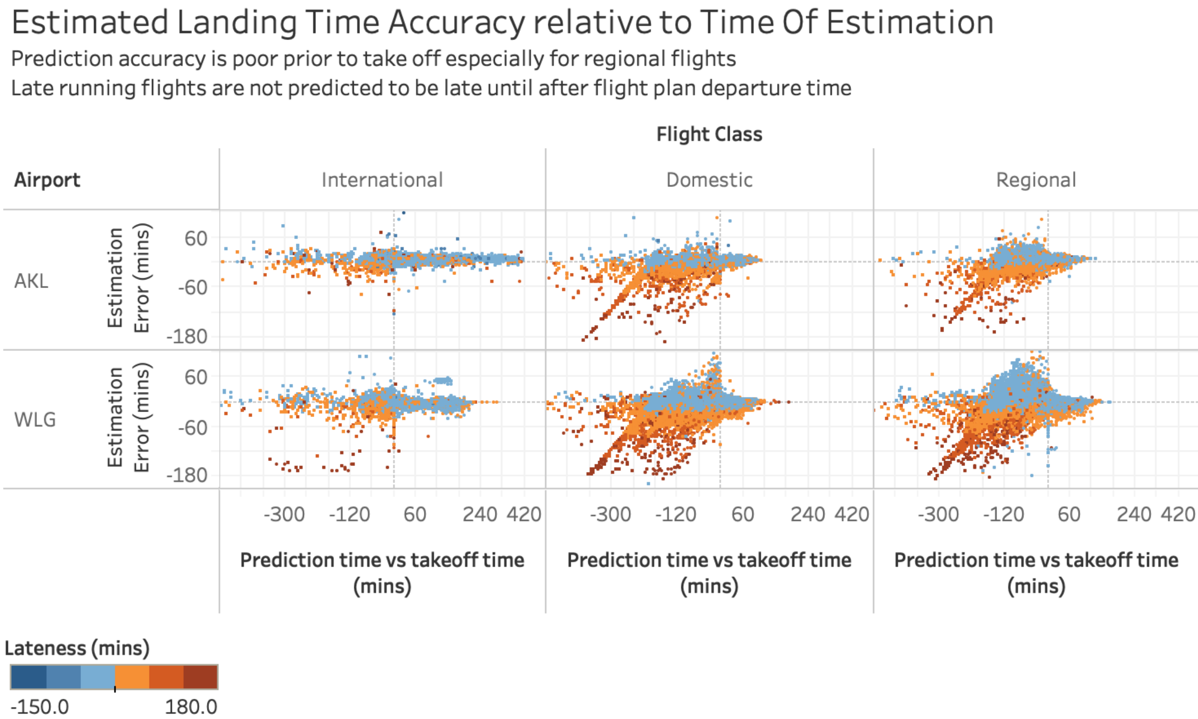

Figure 16 Estimated Landing Time Error Relative to Time of Estimation

Figure 17 below shows the spread of landing time estimation error for the 6 hours prior to landing, and in Figure 18 over the 90 minutes prior to landing. In the background, the estimate is shown for each flight at each 10-minute interval, colour coded to indicate whether the flight has departed from its origin airport. Overlaid, the median, quartile and 5th and 95th percentile ranges of error for arrivals over all.

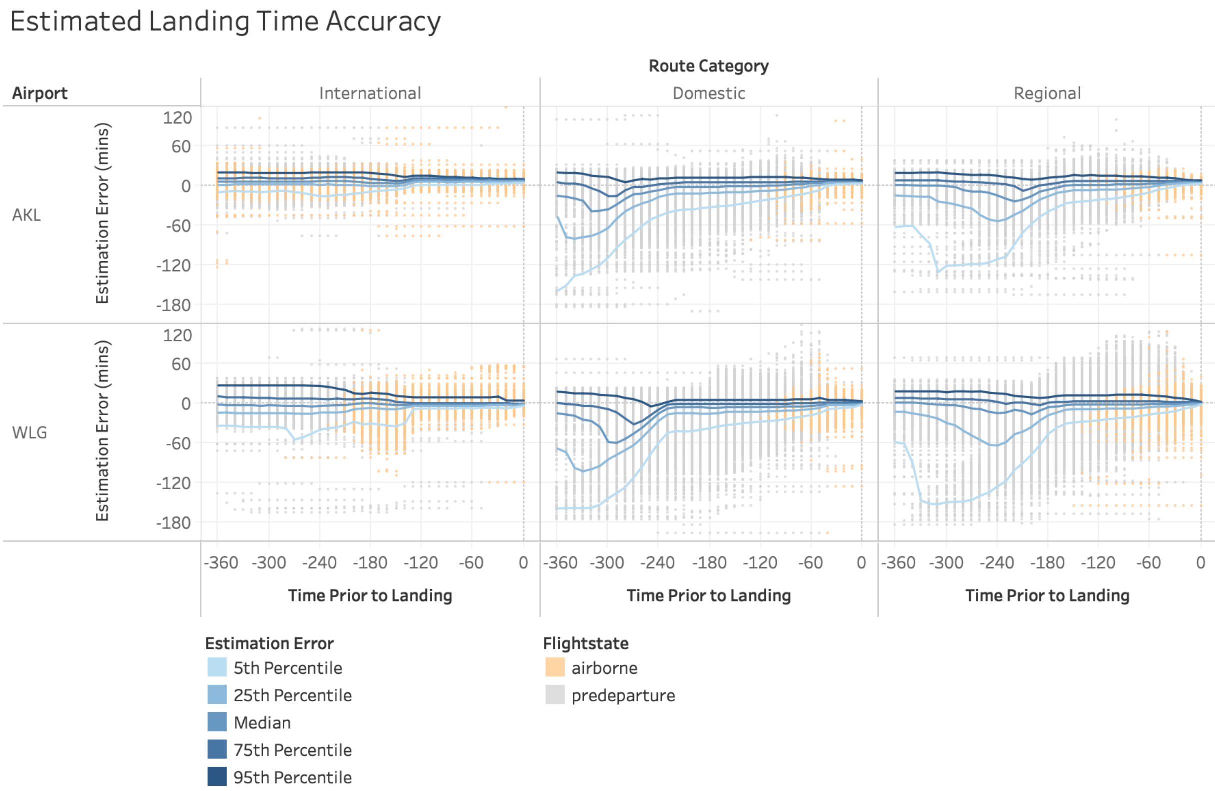

Figure 17 Landing Time Estimate Accuracy Over 6 Hours Prior to Landing

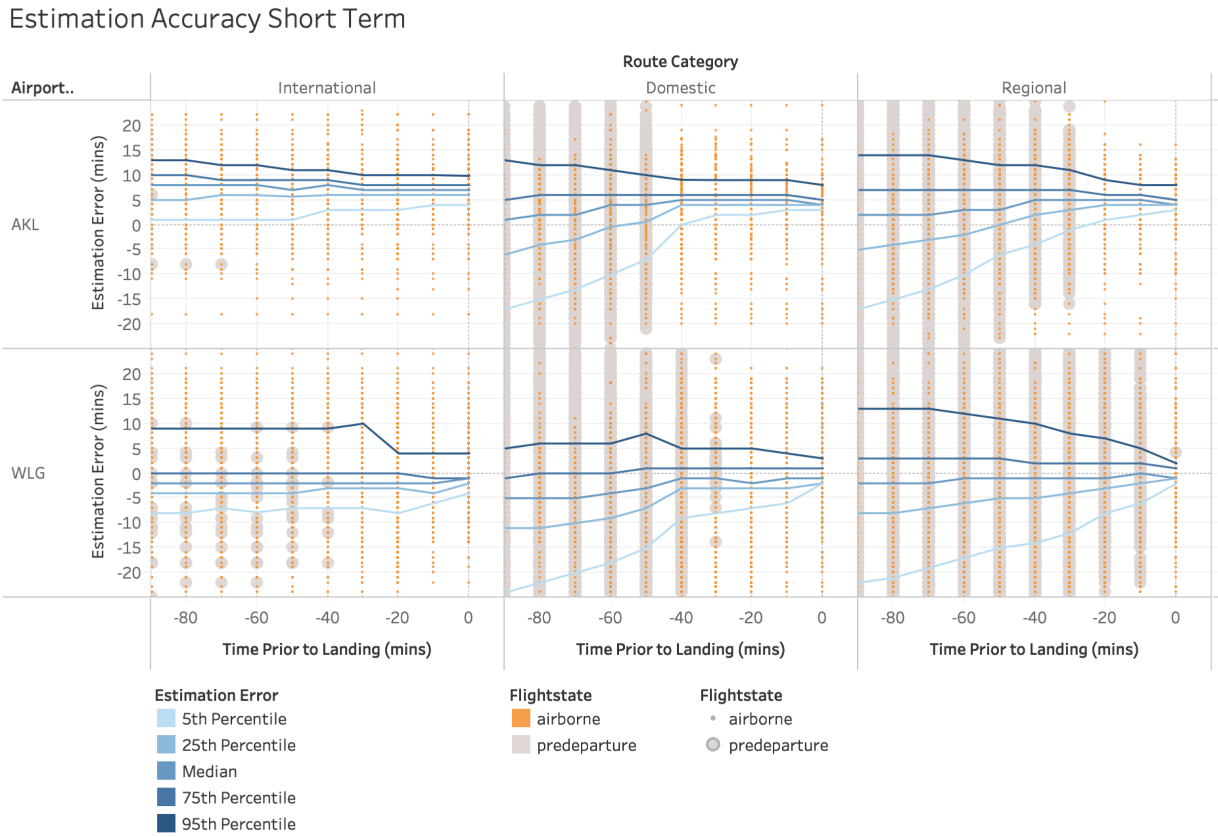

Figure 18 Landing Time Estimate Accuracy Over 90 Minutes Prior To Landing

The spread of estimated landing time compared to actual landing time is broad for flights not yet airborne and a level of error remains for airborne flights, particularly regional flights. Once flights are airborne and in radar coverage, the error in the predicted landing time is reduced, partly because the trajectory times are updated by ongoing surveillance position reports, and partly because the remaining flight time becomes progressively shorter leaving less room for error.

Both Auckland and Wellington have a number of short inbound regional flights, particularly Wellington where flight from Picton, Blenheim, Nelson, Paraparaumu, and Palmerston North have quite short durations. Estimates for these flights continue to have the “pre departure” uncertainty until close to landing time, preventing quality forward planning for stand allocation and turn-round resources.

The data support the evidence from turn-round agents and apron management staff that estimates are highly changeable prior to the flight’s departure. Staff reported the landing estimates for regional flights prior to take off can vary over a range of up to an hour.

Figure 19 shows the estimate history for each flight to Wellington in the available data set, and highlights SoundsAir S8112 for 29 June 2017. The chart shows the estimate at each 10-minute snapshot, so will not necessarily display all estimates received. The estimation for the example flight is 28 minutes early, with 20 minutes to run to the actual landing time at 9:34 am.

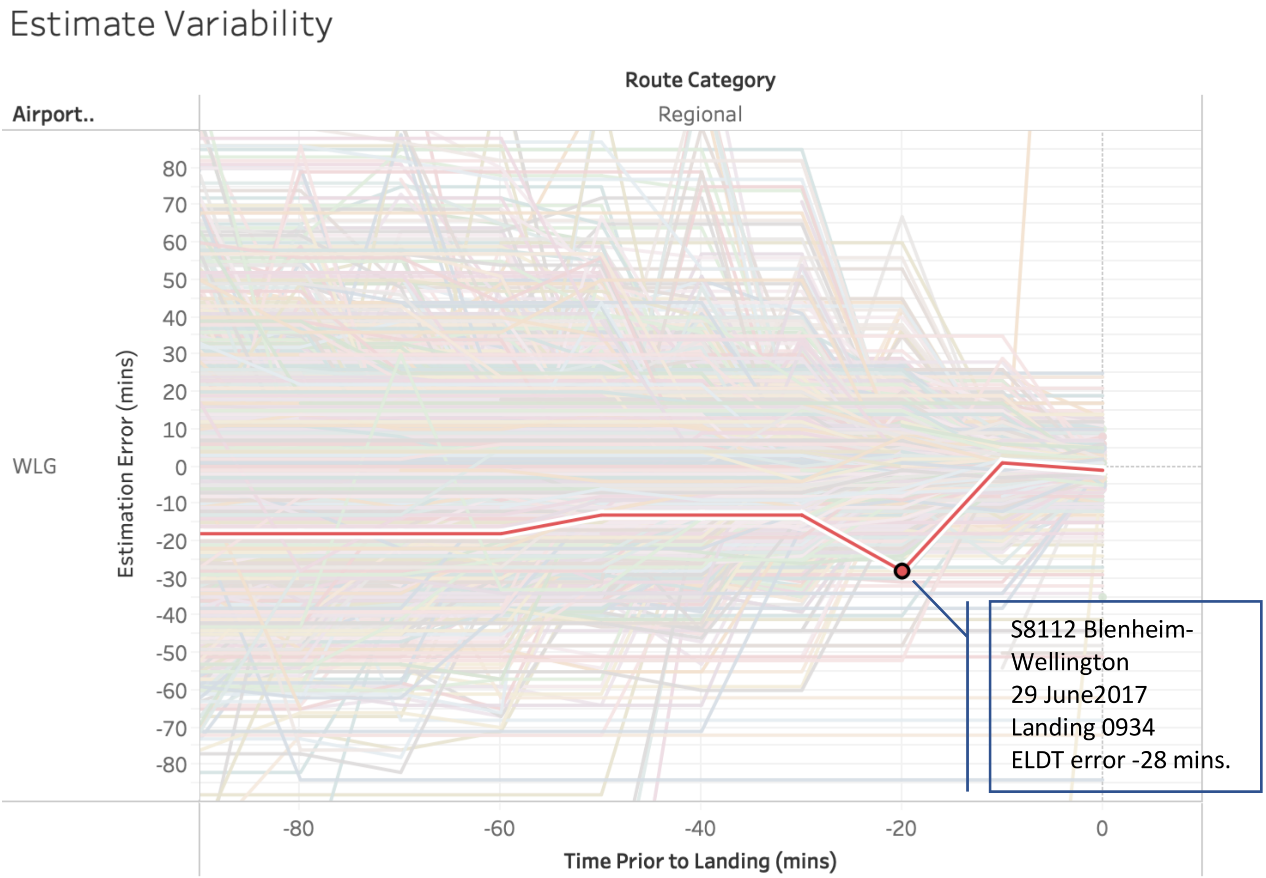

Figure 19 Estimated Landing Time History for Arrivals to Wellington from Nearby Regional Airports

The variability and inaccuracy of ELDT means that apron management staff are unable to plan stand allocation for inbound flights using this data until they are airborne – giving only 10 – 20 minutes notice for flights from the northern South Island to Wellington. Turn-round agency staff ignore estimates for flights not yet airborne, and Wellington Airport filters the electronic feed to also disregard landing estimates for all flights prior to them becoming airborne. All locations at both airports that need landing estimates in advance use "Flightradar24" for that information. The accuracy of ELDT at the required planning time horizon is a lead indicator for the quality of input data to A-CDM.

4.4 Enablers

4.4.1 CPDSP

The implementation challenges around the CPDSP process suggest that a refreshed focus on defining a simple practicable and standard procedure for CPDSP would be helpful. The process would need to address the elements of the A-CDM concept of operations including the time horizon in which TOBT should be accurate and stable, the assurance of TTOT and TSAT being set and communicated with stakeholders including flight crew, and expectations about the timing precision required.

To align surface movement and network flow management, the process should have at least a procedural coupling between TTOT and CTOT for flights to ATFM controlled destinations.

4.4.2 ELDT Accuracy and Stability

A number of data integration services now work with the information required by A-CDM. In particular, it was notable that all locations at both Wellington and Auckland that needed landing time predictions used the FlightRadar24 service for that information. The information that A-CDM needs is increasingly commonly available to the public, with several services like FlightRadar24 providing integrated aviation data electronically. In particular, the services stitch together the sequence of flights of an airframe, allowing late running to become known ahead of time. It may be useful to consider alternative sources of information for predicted flight timing.

4.4.3 A-CDM Mechanisms for Reducing Taxi Out Time

The data indicate that proactively organising surface movements using CPDSP and TSAT to manage surface movement congestion would be effective. Figure 20 illustrates, from two and a half years of Auckland data, that taxi delay and taxi delay variability reduce as start approval delay increases.

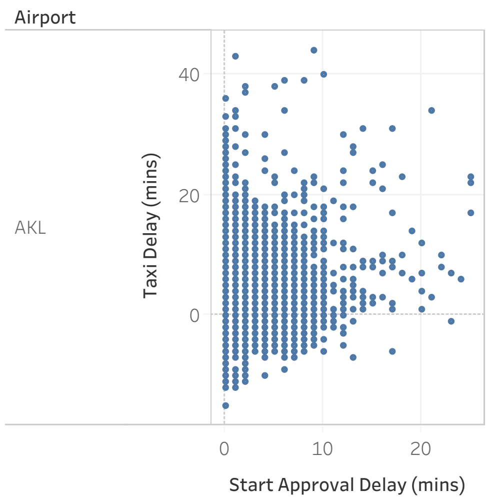

Figure 20 Taxi Delay vs Start Approval Delay

The mechanism for reducing taxi out delays is illustrated below. Taxi out delays are reduced when the surface movement density is reduced. The data for departures is illustrated in Figure 21 on two charts. The charts show the proportion of traffic in 5-minute bands of taxi delay (the limit of precision for the available data)[8], compared on the left with runway flow rate, and on the right with surface movement traffic density, represented by the number of simultaneously taxiing aircraft.

[8] Data quality and taxi delay derivation is listed in Appendix C.

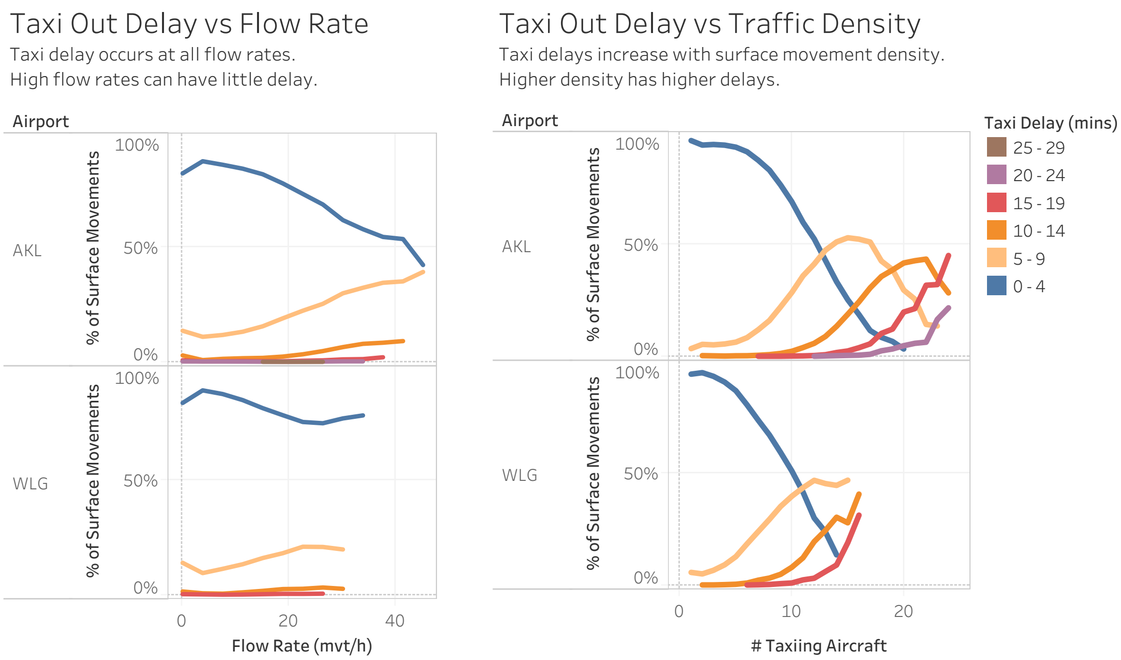

Figure 21 Proportion of traffic delayed vs flow rates and surface movement density

Delays increase somewhat with increasing flow rate yet increase significantly with traffic density. The figure illustrates the general influence of flow rate and traffic density; however, the two factors are not independent. Some of the delays shown in the flow rate chart are due to the effect of increased traffic density, and vice-versa.

To clarify the effect of each, Figure 22 illustrates the average taxi delay relative to the runway flow rate, and surface movement density. Taxi delays increase once a clearly delineated threshold of traffic density has been reached. High flow rates can be achieved without significant taxi delay in a well organised surface movement flow; more powerfully: high flow rates are only being achieved in the presence of low surface movement delays.

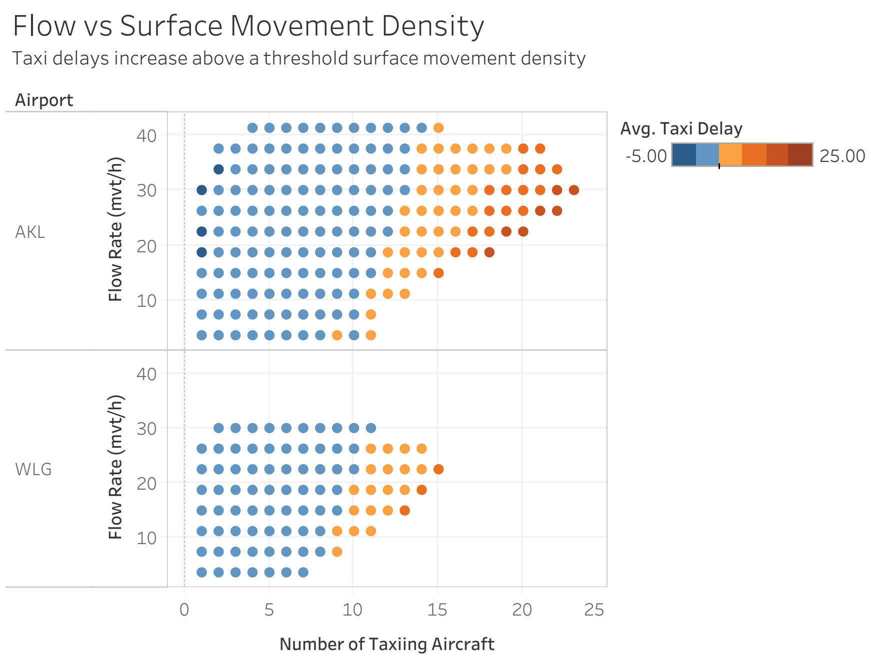

Figure 22 Taxi delay vs traffic flow and density

These data suggest that proactive use of TSAT to delay start approval for departures would be effective in reducing taxi out delays, and that a useful process monitoring metric would measure average peak surface movements.

4.4.4 Destination Oriented On-Time Performance

Both CTOT and TSAT act to delay the movement of a flight. Provided that these controls do not change the eventual take-off or landing times, the CTOT and TSAT off-blocks delays do not affect the resulting block time (including ground holding) and therefore do not further delay the flight. This perhaps counter-intuitive observation has been made for TSAT, and has been confirmed in measurements made for the Eurocontrol A-CDM Impact Assessment. Where TSAT delayed pushback and start, TSAT was found not to have a general effect on punctuality[9].

Three factors are worth noting:

- Moving toward a constraint (runways in New Zealand) that has over demand will inevitably requiring a “busy wait” – either taxi delay, or airborne delay – creating waste and cost.
- The actions of A-CDM controls (discussed in the next chapter) act to delay flights for optimum results at constraints along the journey, requiring timing flexibility prior to arrival.
- The cost of lateness is incurred at arrival potentially allowing flexibility for departures without necessarily incurring additional cost.

This means that it is to an airline’s advantage to be flexible with departure times if the flight is supported by A-CDM decision making around managing demand at constraints. Air New Zealand has recently targeted this exact opportunity, moving to focus on on-time arrival and relaxing targets for on time departure. The practice is at odds with traditional motivations to depart on time, however the variability of flight duration mean that it is not normally possible for a flight to efficiently both depart and arrive on time. The evidence suggests that a focus on arrival punctuality, and flexibility prior to then, would maximise the opportunity for A-CDM to optimise the flight.

4.4.5 Simplified and Automated Data Entry

The challenge of obtaining manual data entry adding to the high workload of turnaround coordinators is not unique. A European research project seeking to optimise A-CDM for middle sized airports also found that time pressure compromised the quality and timeliness of manual entry data.

The study by Aena airports and Eurocontrol Alicante in Spain, as part of the SESAR research programme [11], sought to develop a low-cost, low workload, simplified A-CDM process for smaller European Airports. Alicante has 95,000 movements per year mostly by low cost carriers operating short turn times, ranking Alicante between Auckland and Wellington for traffic levels, yet with high on time turnaround pressures, making the results relevant to New Zealand.

The Alicante research [12] found that:

For TOBT

- TOBT calculations were improved when started earlier. TOBT began being computed prior to the aircraft arrival at the originating airport, prior to the flight to Alicante.
- TOBT could be automated using a statistical model developed from historical data, using sensitivity analysis to identify the factors that are relevant to accurate prediction. These factors included the progress of the flight through the originating airport and, for predicting turn-round time at the local airport, such factors as the operator and type of aircraft, type of stand (contact or remote), and the number of passengers with reduced mobility needing boarding assistance.
- The automatically calculated TOBT would be manually changed only if necessary, usually because of some exceptional event. The research work found that TOBT tended to be stable for 50

[9] [19] Section 2.4.8 page 25

minutes prior to pushback, and the workload of the turnaround handling coordinator was reduced.

For the A-CDM enabled processes the study found it advantageous to:

- Move to event driven predictions. Traffic prediction was more accurate and could be obtained earlier by moving from the use of estimates based on flight plan data (EOBT and ETOT) to target times based on actual aircraft events such as on and off blocks, commencement of boarding and actual take-off time at the prior airport.
- Reduce the number of milestones, to include only those which add value. The study defined seven milestones that encompassed pre-arrival, turnaround, and predeparture sequencing.
- Increase automated data capture to better support statistical methods to find and calculate the impact of different variables on turnaround time, taxi and boarding times.
- Support tower operation by developing an appropriate departure management (DMAN) tool.

4.4.6 Network perspective

From the airport perspective, A-CDM along with ATFM, stand allocation and the turn-round service can be viewed as forming a coherent set of processes which deliver the airport service, from inbound departure at the upstream airport, to outbound departure at the local airport. At a network level, this viewpoint clarifies the way in which A-CDM airports would interact to deliver harmonised operations. over a wider area by coordinating outbound flight timing with the inbound timing at the downstream location.

From the airport perspective:

- ATFM manages inbound flight timing to achieve an efficient approach and on time arrival
- Stand allocation provides facilities at the planned arrival time, and enables flexibility
- The turn-round service prepares the flight in time for an efficient departure
- The predeparture sequencing process CPDSP:
  - times the off blocks movement to minimise taxi time
  - sequences departures with concurrent arrivals so that the runway capacity is best used,
  - times the departure to align with the CTOT window from the destination airport if any, so that flight efficiency at the destination is optimised.

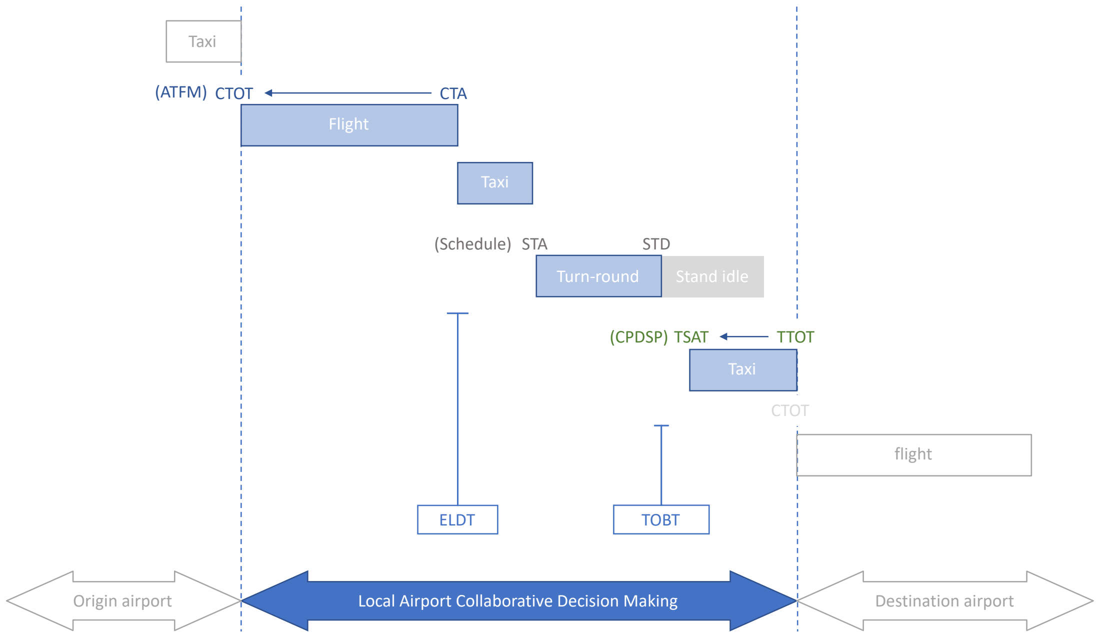

Figure 23 Key aspects of A-CDM applied to a flight turn-round at an A-CDM equipped airport

5 Conclusions

This study has explored the available data on air traffic movements, and the potential for A-CDM in New Zealand at the current stage of maturity of A-CDM practice.

The potential benefits of A-CDM include reduced waste in taxi time, improved runway throughput, improved approach efficiency and reduced block time. The recommended metrics measure these factors and separately capture the contribution of A-CDM processes and other infrastructure improvements.

The value of reduced taxi time is in the low NZ$M, and the value of improved on time performance is a similar order of magnitude, suggesting that viable business cases could be made for realising this value. Although the basic data exchange for A-CDM has been established, work is required to implement the collaborative predeparture sequencing process, and raise the quality of traffic demand prediction at the required planning horizon.

Reducing taxi time would require departures to be held briefly at the stand using TSAT, and communicating TSAT to flight crews. The planning horizon for the departure planning process is short and likely to be satisfied by the existing TOBT data, making this a feasible near-term goal.

Optimising runway throughput, approach efficiency, and stand allocation requires a planning horizon longer than domestic flight durations. To enable realising these benefits, the quality of predicted landing demand (ELDT) and predicted departure demand (TOBT) would need to improve, and the pre-departure sequencing process extended to include ATFM. The availability of commercial data aggregation sources such as FlightRadar24, and European research suggest that improving demand prediction is feasible.

The different level of investment required for each pool of benefits suggests a two stage A-CDM development process.

5.1 Recommendations

Stakeholders could consider a staged course of action to realise A-CDM benefits, first realising taxi out savings using existing short-term departure demand prediction (TOBT), and secondly improving on time performance and approach efficiency through improved use of runway and stand capacity by improving the quality arrival and demand prediction.

Stage	Outcome	Components
1	Establish performance metrics proposed in this study	
2	Reduce taxi-out delays	
		Formalise the pre-departure sequencing process
		Make TSAT available to flight crews
3	Improve approach efficiency, runway efficiency, and on time performance	
		Develop trustworthy ELDT and TOBT (automated as much as practicable) with a 70+ minute horizon
		Include departures in ATFM planning for inbound arrivals
		Incorporate flight schedule in sequencing decision making to improve on time performance for marginally late flights
		Optimise stand allocation

5.2 Proposed Metrics

To capture A-CDM benefits the proposed metrics track three broad performance areas

- Direct operating costs for aircraft operators
- Block delay, indicating the impact of capacity constraints on schedules and on-time performance
- Capacity utilisation, indicating the efficiency with which the available resources are used

It is possible to measure directly the benefits arising from the A-CDM collaborative predeparture sequencing process, including the trade-offs and compromises that naturally occur where the flows of arriving and departing traffic meet at runways and gate stands. Metrics have been identified to measure the leading locations where delay occurs: holding for the runway on the ground or in the air, and waiting for a gate stand to become available.

The metrics separately account for the costs of avoidable delay, and also account for the impact of traffic congestion on schedule block times. They also accommodate changes in traffic volume and infrastructure and are able to separate baseline changes due to infrastructure evolution from the tactical operational values being measured. For any metrics where the aircraft is in motion (taxi and approach delays, and runway efficiency) the baselines are the normal unimpeded case, as demonstrated in practice.

Benefit Area	Metric	Baseline
Direct Operating Cost Efficiency	For delayed flights, the change over time in • average taxi-out delay time (excluding start delay) and cost (including start delay) • average taxi-in delay time and cost	Unimpeded taxi time for the runway-stand pair used by the flight.
	For delayed flights, the change over time in: • average approach delay time and cost	Unimpeded flight time for shortest applicable approach procedure for the city-runway pairs used by the flight.
Block Delay	For delayed flights, the change over time in: • average taxi out delay (including start delay) • average taxi in delay • average approach delay	A selected reference time as required (may be specific to an experiment, or nominal for long-run metrics), and applicable flow rate where appropriate.
Capacity Utilisation	Change over time in • % of flights delayed on taxi-out • % of flights delayed on approach • % of flights delayed on taxi in • % of flights delayed waiting for stand	Selected reference time as required (may be specific to an experiment, or nominal for long-run metrics), and applicable flow rate where appropriate.
	For delayed flights (departure or arrival), the change over time in runway efficiency	Demonstrated runway capacity in the weather and traffic mix conditions.

Table 11 Proposed A-CDM Benefits Metrics

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Appendix A Information Sources

A.1 Interviews

From site visits and interview, we were able to obtain qualitative descriptions of the processes that are in place, and the experience of A-CDM from stakeholders across the operational spectrum. Information about airport and airways processes was obtained through interviews with specialists at the following locations, organisations or functions:

Auckland International Airport

- Service Transformation Manager - Technology
- Auckland International Airport international ramp control centre
- Staff at Air New Zealand domestic ramp control centre
- Operations Manager - Menzies international (International gate agent)

Wellington International Airport

- Manager Airport Performance
- Policy and Procedures Coordinator
- Staff at Air New Zealand domestic ramp operations centre

Airways

- Auckland Tower
- Auckland Approach Sector
- Wellington Tower
- Airways flow control CAM coordinator,
- A-CDM technical specialist

Air New Zealand

- On Time Performance Manager
- Manager Regulatory Affairs

Sounds Air

- Operations Manager

A.2 Data

Wellington and Auckland airports have furnished complete sets of data from the airport operating system records for the period since the commencement of the A-CDM facility through to early 2018. Two sets of data have been made available:

- A record for each aircraft turn-round in the period, containing scheduled, estimated, and actual values for key milestones (landing, on blocks, off blocks, and take-off), and a selection of A-CDM milestone events
- A set of updates events per turn-round covering part of the same period, containing updates to estimates as the flight or turn-round progresses.
- Samples of internal reporting as used in early 2018 to assess A-CDM performance

The data set contains the available A-CDM information about each aircraft turn-round at the airport and, separately, detailed individual update events related to each turn-round for a range of time as follows:

Aircraft turn-round records

Airport	Number of records	Start Date	End Date
Auckland	208,113	4 June 2015	27 May 2018
Wellington	72,823	13 April 2016	27 February 2018

Detailed event records

Airport	Number of records	Start Date	End Date
Auckland	3,667,173	29 March 2018	29 June 2018
Wellington	13,118,113	10 October 2016	10 October 2018

Appendix B Defining a Runway Capacity Table

Runway capacity in these metrics is defined empirically, in terms of “demonstrated capacity” as a flow rate that has been demonstrated in practice in the historical data.

Runway capacity is variable and depends not only on the present weather (wind, cloud ceiling, and visibility as they affect the allowable procedures for safety reasons) but also the precise mix and sequence of traffic. The dominant factors are the general ratio of arrivals to departures over a relevant period, the separation requirements in the present weather conditions, and the specific spacing required between aircraft pairs in detail.

To fairly represent runway efficiency, it is therefore essential that the reference capacity used in the runway efficiency calculation be context sensitive, and appropriate to the immediate conditions.

The arrival departure ratio is a factor that metrics should take into account.

As an illustration, Figure 24 and Figure 25 show the demonstrated runway capacity at Auckland and Wellington in the period covered by the data. In these charts, each dot represents a runway output condition that has been demonstrated at least 50 times during the sample period. The frequency of occurrence depends on whether demand exists, so it is to be expected that the high flow rates occur less frequently, nonetheless the values shown have been often demonstrated.

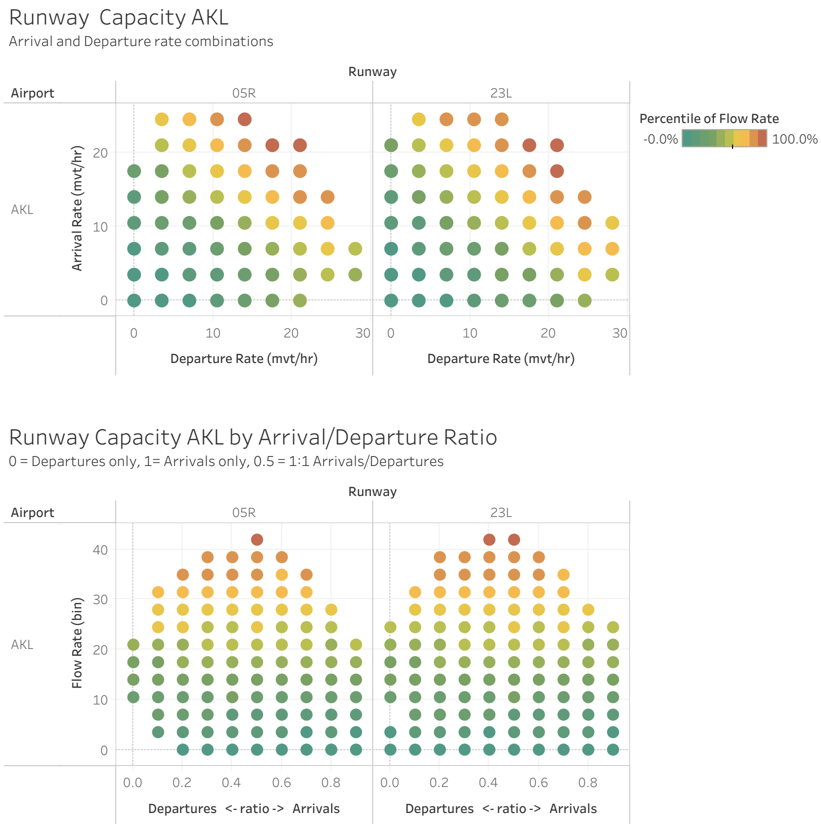

Figure 24 Auckland demonstrated runway capacity

From the lower chart, peak throughput overall is normally achieved near 1:1 ratio of arrivals and departures, and falls away as the mix of traffic becomes dominated by arrivals or departures. The change in output varies by more than 40% depending on the ratio of arrivals to departures. This means that the reference capacity for the efficiency metric must acknowledge the arrival/departure ratio of the traffic being measured.

From the upper chart, the peak rate for arrivals differs from the peak rate for departures. Achieving the higher rates for either arrivals or departures can only occur when that class of movement dominates the traffic mix. The highest arrival rate occurs when there are few departures, and vice versa. This suggests that well considered sequencing by the A-CDM predeparture sequencing process could have a beneficial effect on runway throughput.

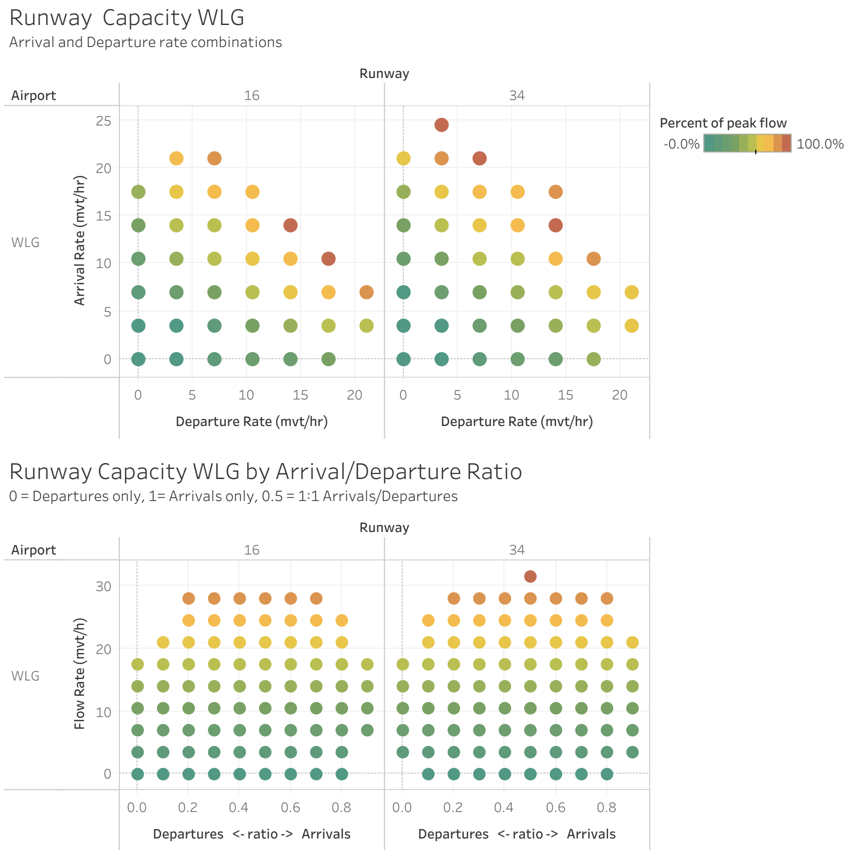

Figure 25 Wellington demonstrated runway capacity

The charts above are taken from the entire available data set and therefore represent the peak demonstrated throughput during the period for good weather conditions that do not restrict the runway capacity. In production, the runway capacity would also be measured for various conditions that reduce capacity, and the appropriate value for the prevailing conditions used when calculating the efficiency metric. For production metrics, a figure fairly representing reasonable capacity expectation should be used. The FAA use the 95th percentile of demonstrated capacity[10].

[10] [10] section 3.2.2, page 31

Appendix C Summary of modelling assumptions

C.1 Ground Operations

C.1.1 Flow Rate

The runway flow rate is computed as the average elapsed time between aircraft during a 30-minute window before each movement. This measures the flow of the traffic specifically relevant to creating congestion or delays for each individual aircraft.

To aid readers, the resulting flow rate in minutes per aircraft is inverted and scaled so that the analysis can be presented in familiar terms of movement per hour.

C.1.2 Taxi Time

The data include landing and take-off time, and on and off blocks times. These are obtained from a variety of sources, including manual entry, with varying quality and time quantisation.

Data	Origin	Time Quantisation
Actual landing time (ALDT) Actual take-off time (ATOT)	ATC Radar	1 Minute
Actual In blocks time (AIBT) Actual off blocks time (AOBT)	Manual entry by ground handler, or automatic aircraft records via ACARS recording manually transcribed	1 – 5 Minutes

The variable time quantisation time and questions about the accuracy of manually entered data means that this analysis is necessarily approximate. Where necessary data has been grouped in 5-minute bins to avoid statistical sampling artefacts, median values are used within groups, and statistics are taken over large samples to minimise the impact of variable data quality (assuming that inaccuracies are normally distributed).

Taxi delays for each flight are computed as

Actual Taxi Duration – Reference (Unimpeded) Taxi Duration

Where

Actual Taxi Duration (landings) = AIBT – ALDT

Actual Taxi Duration (departures) = ATOT - AOBT

Reference Taxi Duration = lower quartile of actual taxi duration for each runway to stand route where the airport flow rate is no more than 12 movements per hour, and the surface movement density is at most 4 aircraft.

With few exceptions, the standard deviation for the default taxi time is between zero and 2 minutes and less than 40% of the taxi duration. Sample sizes for most routes are greater than 20, and up to 1200.

To compensate for variable time quantisation in the data, totals for taxi delay have been computed as follows:

Bin the computed per-flight delay into 5-minute bins
In each bin, compute the median taxi delay and the number of movements
Total delay per bin = Number of movements x median delay for the bin

The figures have been annualised by selecting a source time period of exactly 52 weeks, to remove the effect of day-of-the-week variations, and for which full data was available for both airports. Taxi delays above 30 minutes are ignored, on the basis that higher delays are increasingly likely to result from extraordinary events or data entry errors. The results are in Table 12.

C.1.3 Cost of taxi delay

The uncertainty around delay figures mean that the cost figures for taxi delay costs are therefore representative and approximate, for the purpose of indicating the order of magnitude value of process improvements. The estimate uses the following approximations for aircraft and fuel costs.

Extensive research on delay costs by the University of Westminster for Eurocontrol and the European Performance Review Unit showed that the cost of delay for aircraft is quite non-linear. The costs include both the per-minute direct operating costs, the costs of running late compared with schedule, and the costs of building in compensating schedule slack [6].

This analysis separates the immediate time required for taxiing from the costs related to on time performance, allowing taxi delay to be assessed at the simple marginal aircraft direct operating cost.

From Air New Zealand supplied figures (Table 13) we extract the time varying costs of flight excluding fuel, using a nominal hourly rate representative of the range of values in the data.

The movement data from the airports data does not contain information about aircraft types, but does classify the route of the flight (international, domestic jet, domestic regional). To give an indicative cost of time, we use representative aircraft for each class, subdividing the international category into Australia and all others, and using narrow body jet costs for the Australian flights.

Aircraft Category	Tuboprop	Domestic Jet	International Jet
Representative Type	ATR72	A320	B777-300
Idle fuel flow (kg/min)	6.1	15.4	22.8
Fuel cost (NZD/min)	5.7	14.3	21.2
Marginal direct operating cost (excluding fuel)	14.9	37.0	61.0
Total NZD/min	21	51	82

Sources: European airline delay cost reference values [13], ICAO engine emissions databank, Air New Zealand summary operational costs data

Fuel costs are estimated using recent price history available from the IATA Jet Fuel Price Monitor [14]. The price in USD/bbl. is converted to NZD at the recently prevailing rate of 0.69 USD/NZD, and to kg using 125litre/bbl. and 0.79kg/litre.

Jet fuel has varied around USD80/bbl. more or less since November 2017. This corresponds to 0.92 NZD/kg. Fuel costs vary substantially over time, however during taxi the other marginal operating costs of the aircraft dominate the cost of waiting time.

Airport	Route Category	Taxi Delay Band	Direction: ARR # of movements	Direction: ARR Median Taxi Delay (mins)	Direction: ARR Total Taxi Delay (mins)	Direction: ARR Cost of taxi delay	Direction: DEP # of movements	Direction: DEP Median Taxi Delay (mins)	Direction: DEP Total Taxi Delay (mins)	Direction: DEP Cost of taxi delay
AKL	Intl. wide body	35 - 39	9	36	324	26,568	4	38	152	12,464
		30 - 34	16	32	504	41,328	6	33	195	15,990
		25 - 29	40	27	1,080	88,560	6	26	156	12,792
		20 - 24	69	22	1,518	124,476	36	21	756	61,992
		15 - 19	149	16	2,384	195,488	92	16	1,472	120,704
		10 - 14	285	11	3,135	257,070	530	11	5,830	478,060
		5 - 9	733	7	5,131	420,742	2,185	7	15,295	1,254,190
	Intl. narrow body	35 - 39	1	38	38	1,938				
		30 - 34	4	30	120	6,120	6	32	189	9,639
		25 - 29	6	27	159	8,109	5	27	135	6,885
		20 - 24	21	21	441	22,491	13	22	286	14,586
		15 - 19	35	17	595	30,345	65	16	1,040	53,040
		10 - 14	116	11	1,276	65,076	339	11	3,729	190,179
		5 - 9	279	7	1,953	99,603	1,348	7	9,436	481,236
	Domestic	35 - 39	3	36	108	5,508	1	36	36	1,836
		30 - 34	2	34	67	3,417	6	33	195	9,945
		25 - 29	8	26	208	10,608	13	27	351	17,901
		20 - 24	10	23	225	11,475	43	21	903	46,053
		15 - 19	21	16	336	17,136	129	16	2,064	105,264
		10 - 14	45	12	540	27,540	782	11	8,602	438,702
		5 - 9	142	7	994	50,694	3,232	7	22,624	1,153,824
	Regional	35 - 39	3	36	108	2,268	3	36	108	2,268
		30 - 34	5	31	155	3,255	14	31	434	9,114
		25 - 29	4	28	110	2,310	16	26	408	8,568
		20 - 24	21	22	462	9,702	64	21	1,344	28,224
		15 - 19	35	17	595	12,495	270	16	4,320	90,720
		10 - 14	102	12	1,224	25,704	1,589	11	17,479	367,059
		5 - 9	250	7	1,750	36,750	5,437	7	38,059	799,239
WLG	Intl. wide body	20 - 24	1	20	20	1,640				
		15 - 19					1	15	15	1,230
		10 - 14	2	14	27	2,214	1	10	10	820
		5 - 9	11	6	66	5,412	2	7	14	1,148
	Intl. narrow body	25 - 29	2	28	56	2,856				
		15 - 19	4	16	64	3,264	7	16	112	5,712
		10 - 14	5	13	65	3,315	40	12	460	23,460
		5 - 9	12	7	84	4,284	163	7	1,141	58,191
	Domestic	25 - 29	2	26	52	2,652				
		20 - 24	11	21	231	11,781				
		15 - 19	49	16	784	39,984	21	16	336	17,136
		10 - 14	96	12	1,152	58,752	173	11	1,903	97,053
		5 - 9	122	7	854	43,554	994	7	6,958	354,858
	Regional	30 - 34					1	32	32	672
		25 - 29	7	25	175	3,675				
		20 - 24	20	22	440	9,240	7	21	147	3,087
		15 - 19	93	16	1,488	31,248	73	16	1,168	24,528
		10 - 14	280	12	3,360	70,560	423	11	4,653	97,713
		5 - 9	599	7	4,193	88,053	2,172	7	15,204	319,284

Table 12 Taxi Delay Estimates.

AIRCRAFT TYPE	B777-200	B777-300	B787-900	B787-900	B787-900	B787-900	A320-200	A320-200	A32D-200	A32D-200	AT7	AT7	DH3	DH3
Aircraft Category	HJ	HJ	HJ	HJ	HJ	HJ	MJ	MJ	MJ	MJ	TP	TP	TP	TP
SECTOR	AKL-HKG	SFO-AKL	PVG-AKL	HNL-AKL	EZE-AKL	PER-AKL	CHC-BNE	AKL-SYD	AKL-CHC	AKL-ZQN	TRG-AKL	CHC-WLG	CHC-NSN	PMR-HLZ
Nominal Duration (Hours:Minutes)	11:31	12:50	11:30	09:00	13:30	06:10	04:00	03:35	01:25	01:50	00:35	01:00	00:55	00:50
Nominal Duration Minutes	691	770	690	540	810	370	240	215	85	110	35	60	55	50
TOTAL VARIABLE OPERATING COSTS	155,361	192,348	122,494	84,673	97,405	70,139	23,940	23,373	10,358	13,222	2,079	3,565	2,872	2,872
Total marginal time related costs reported	50,473	52,605	36,098	31,828	25,547	19,398	10,033	9,565	2,570	3,445				
Turboprop Variable Estimate (26% of total variable costs)											541	927	747	747
Percentage of variable costs	32%	27%	29%	38%	26%	28%	42%	41%	25%	26%	26%	26%	26%	26%
ADOC per minute	73	68	52	59	32	52	42	44	30	31	15	15	14	15
Source: Air New Zealand airline cost per sector sample data 2017. Duration and cost per minute by Mahino Research														
Aircraft category: HJ : Widebody jet, MJ: Narrow body jet, TP: Turboprop. Marginal costs exclude the cost of fuel														

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Table 13 Summary of Aircraft Direct Operating Costs excluding fuel