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Memo *To:* *Simon Zweighaft, Infraconsult LLC* *cc:*

From: *Tom Parkinson P.Eng* *Date:* *30 January 2009*

Subject: *Honolulu High-Capacity Transit Corridor Project*
Review of parts of the PMOC Spot Report [Rev 1]

Introduction

This memo reviews sections of the PMOC Spot Report (Jacobs) of December 2008 with specific respect to dwell times and fleet size. A train performance program was run with various criteria to confirm or adjust the provided station-to-station travel times. Fleet size was then estimated for the projected 2030 ridership, for a variety of different parameters, including a possible short-turn at Leeward CC and other ways to reduce the fleet size.

Traction Power Supply

The spot report expresses concern at reduced performance at times of low voltage. Traction power supply design is routine with sub-station (and feed) capacity planned to accommodate the loss of any single sub-station. At such times line voltage will drop and train performance and capacity will be reduced. Such circumstances are so rare that they are not taken into account in fleet estimates.

There is no reference to any energy saving strategies. These include 1) variable voltage sub-stations that enable adjacent sub-stations to share load and so reduce demand charges; 2) receptive sub-stations that accept regenerative power when other trains on the line cannot; 3) train control systems that monitor and adjust station departure times so that trains in the same power section do not accelerate simultaneously; and 4) slightly reducing acceleration rates and maximum speeds to conserve energy. The first two strategies incur capital costs and complexities and are rare—usually only in cities with high electricity costs. Strategy 3) incurs irregular but minor delays within layover time correction; but 4) increases travel time and so is either disabled at peak times or must be accommodated in travel time and fleet size estimates.

Train Control System

The specification for automatic train operation (ATO) is important as manual driving increases travel times and so fleet size by 5–8%. Attended automatic driving is assumed in the analysis in this memo. It is unstated whether the attendant or the train control system[1] will control dwell times. As headways are well within typical automatic train control capabilities, the issue of a “controlling dwell time” is irrelevant and the type of train control system dwell management should not influence fleet size.

Peak Hour Factor

The spot report uses the default peak-hour factor of 0.80. This heavy rail “factor” is generous for a medium capacity transit system such as Honolulu and so provides a margin in the fleet calculations. Some demand models can estimate the 15-minute peak within the peak. This should be checked. A few light metro or light rail systems have a smaller or no peak within the peak, and, if so in Honolulu, the fleet size can be reduced.

Vehicle Capacity

[1] An attendant would be able to override pre-set dwell times. Some irregularities in dwell times are inevitable, but are usually within the margin provided for turn-around and recovery at the ends of the line, and so need no allowance.

The spot report gets into more detailed analysis and calculation than appropriate given the uncertainties in vehicle size[2] at this stage in the project. Although the preliminary specifications suggest a vehicle 60 feet long by 10 feet wide the fleet size is too small to justify a “custom” size without a cost premium. Metro (subway) cars range from 15.5 to 23 metres (47 – 75 feet); a common size is 20 metres or 66 feet[3]. The generally accepted loading standard for North American and Western European systems is four standing passengers per square metre (2.7 sq. ft. / standing passenger), lower than the 3.2 sq. ft. / standing passenger of the specification. At this stage it would be best to consider car capacity in a range, in all cases with the specified 50 seats per car:

	Car Size – feet	Sq. ft /standee	Capacity
Specifications	60 x 10	3.2	168
Maximum	66 x 10	2.7	210

The resultant headways and fleet size are calculated for this range later in this memo.

Station Dwell Times

The report uses the complex math of TCRP 13 Rail Transit Capacity, Chapter 4, to calculate dwell times. The results are intuitively too high. This math is intended for high volume rapid transit systems to determine the controlling dwell and so the closest headway and maximum line volume. It is inappropriate and unnecessarily complex for the more modest volumes, longer headways and short trains in Honolulu.

TCRP 13 suggests using simple methods where possible. The Parsons Brinckerhoff estimate of 20 seconds average per station is reasonable and can be checked by reference to Figure 4.6 of TCRP 13 which shows an average 1.86 seconds per passenger, boarding or alighting, with level loading. The results (rounded) are shown to the right for cars with two and three double stream doors and headways of 3.5 and 3.0 minutes.

	15 minute	3.5 min headway		3.0 min headway	
	On+Offs[4]	2 doors	3 doors	2 doors	3 doors
East Kapolei	370	20 sec	13 sec	17 sec	11 sec
UH West O’ahu	404	22 sec	15 sec	19 sec	13 sec
Ho’opili	87	5 sec	3 sec	4 sec	3 sec
West Loch	264	14 sec	10 sec	12 sec	8 sec
Waipahu T. Cen	122	7 sec	4 sec	6 sec	4 sec
Leeward CC	55	3 sec	2 sec	3 sec	2 sec
Pearl Highlands	642	35 sec	23 sec	30 sec	20 sec
Pearlridge	236	13 sec	9 sec	11 sec	7 sec
Aloha Stadium	101	5 sec	4 sec	5 sec	3 sec
Ala Liliko’i	246	13 sec	9 sec	11 sec	8 sec
Middle Street	132	7 sec	5 sec	6 sec	4 sec
Kalihi	186	10 sec	7 sec	9 sec	6 sec
Kapalama	83	5 sec	3 sec	4 sec	3 sec
Iwilei	109	6 sec	4 sec	5 sec	3 sec
Chinatown	61	3 sec	2 sec	3 sec	2 sec
Downtown	442	24 sec	16 sec	21 sec	14 sec
Civic Center	169	9 sec	6 sec	8 sec	5 sec
Kaka’ako	117	6 sec	4 sec	5 sec	4 sec
Ala Moana Center	1009	55 sec	36 sec	47 sec	31 sec
Average[5]		**11.5** sec	**7.7** sec	**9.9** sec	**6.7** sec

The terminal stations accommodate these longer dwells through their turn-around layover. All averages are well below 20 seconds. When preparing an operating plan some dwells can be adjusted to 15 seconds, and those at Pearl Highlands and Downtown increased to 35 and 25 seconds respectively. Ala Liliko’I is the only station with significant doorway cross-flows but 20 seconds is still adequate.

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2 — and the amount of space lost to operator/attendant cabs and any equipment cabinets, both car design specific.
3 The maximum size for a 3-car train to fit on the 200 foot Honolulu platform.
4 15 minute, peak within the peak, ons and offs from Spot Report Table 4.5, AM Peak Direction only
5 Averages excludes Ala Moana terminal dwell

Although these dwell data show that cars with three doorways are not necessary, three are common on metro cars of this size and are recommended as they better accommodate common situations where a wheelchair, pushchair, stroller or bicycle obstructs a doorway — or where staff has to isolate (temporarily bar) a defective door pair. Layover and recovery time is normally divided between the terminal stations with the majority at one end to give the attendant time for relief. In this case the great majority of this time should be provided at Ala Moana Center with its higher passenger flow.

Round Trip Time

This section of the spot report (called *cycle time*) is unnecessarily long and complex and time prevents a detailed critique. The work is based on the station-to-station travel times provided by the City. These times presumably originate from a Train Performance Model which typically analyses the trains motion second by second, accommodates grades and curves, or other speed restrictions, plus adds nuances such as fluctuations in third-rail voltage — but rarely reflects operational practicalities. As a result these models often underestimate realistic travel times

For example, in automatic train operation the train does not maintain its maximum speed of 55mph over sections where this is allowed. Rather it accelerates the train to 55mph then lets it coast to a set point, say 50 or 52 mph before commanding acceleration again, similarly, but less significantly, with braking—so avoiding so-called “traction hunting”. The models also rarely allow for the delays that occur between say, commanding service braking[6] — and achieving that rate — 1 to 3 seconds later. These reaction times (plus additional reaction times for any manual driving) occur several times each station-to-station run and accumulate in a round trip.

Although the vehicle specifications call for a maximum speed of 55 mph and a maximum (initial) acceleration rate of 3.0 mphps it is preferable to assign lower rates to normal service for three reasons. One is to leave some catch-up margin to accommodate a delayed train, the second is to conserve energy and lower wear and tear and hence maintenance; and the third is due to variation between equipment that increases as the rolling stock ages. In a fleet of otherwise uniform rail cars, performance can vary by as much as 10% between older trains.

The Transport Consulting Limited Train Performance Model was run for both full and realistic performance criteria using station-to-station distances[7]. No grade or curve data was available but an examination of the alignment shows only one curve, east of UH West O’ahu station with a small (due to proximity to the station) consequence on performance. A manual adjustment of 10 seconds was applied. Grades, unless severe, tend to balance out on a round trip. Time permitted only a unidirectional run, which is then doubled for a round trip. The error this introduces will be small. Dwells are as shown, adjusted according to the above tabulation from 15 to 35 seconds. At light volume stations dwells lower than 15 seconds may be possible but generally 15 seconds is the lowest recommended time—as dwells include approximately 5-7 seconds for door opening and closing times plus system “reaction” times (stationary delays).

The TCL Train Performance Model is metric only. The following conversions apply:

- ***Full performance*** ***55mph = 88.5 km/h max;*** ***3.0 mphps = 1.34 m/s²***
- ***Realistic performance*** ***49.7 mph = 80 km/h max;*** ***2.46 mphps = 1.1 m/s²***

[6] The sport report has a typographic error, quoted a too low figure for service braking.
[7] The model component for at-grade operation that adds intersection approach delays and traffic signal waits was disabled.

A second module of the performance model estimates the round trip time from end-to-end travel times. Two variables are applied; one is a terminal approach delay to allow for speed reductions over the terminal crossovers and the desirable slower entry into a dead-end terminal station; the second is the layover time. Typically this would be set at 7 to 10% of the running time. (Union agreements on some systems specify this percentage.) This time is distributed between the two terminals with the majority at one end of the line to provide operator relief (unless operator setback is used). The minimum time must allow the operator to “change ends”. As the trains are short, and are expected to have the now almost standard feature of walk-through gangways, the operator will take less than a minute to walk through the train, check there are no remaining passengers (the euphemism “sleepers” is used) and remove any left property or large garbage. This should be at the Ewa end of the line with the longer layover at Ala Moana with its large passenger flow.

The following screenshot shows the full performance run. Orange/yellow cells are for input.

	A	B	C	D	E	F	G	H	I	J	K
1	**Honolulu Light Metro TRAVEL TIME - Transport Consulting Ltd Train Performance Model**										
2	**Fully grade separated FULL PERFORMANCE Auto Driving, 55mph max speed; 3.0mphps**										
3	**Times based on normal performance Light Metro Vehicle**				Maximum speed		88.5	km/h	n/a	km/h approach	
4	Speed Margin	1.02	constant		Accel&brake rate		1.34	m/s^2	n/a	km/h at grade	
5	Operating margin	2	seconds		System reaction time		1.5	seconds	88.5	km/h segregated	
6	Train Length	35	metres		Jerk limiting time		0.5	seconds	n/a	pre-empt +/- sec	
7	Switch time	0	seconds		Base Station Dwell		20	seconds	n/a	signal cycle sec	
8	Constant	0			Station Length		61	metres	orange =	input data	
9											
10	**STATION**	**Meterage**	**Distance**	**Sector**	**Time**	**Dwell**	**Manual**	**Delay**	**Total**	**Cumulative**	
11	East Kapolei	11887	metres	max km/h	Seconds	Seconds	adjustment	for	Seconds	Seconds	
12	UH West O'ahu	13472	1585	88.5	98.3	25	0		123.3	123.3	
13	Ho'opili	14966	1494	88.5	94.5	15	10	curve	119.5	242.8	
14	West Loch	17617	2652	88.5	142.6	20	0		162.6	405.4	
15	Waipahu Transit Center	19711	2094	88.5	119.4	20	0		139.4	544.8	
16	Leeward CC	21991	2280	88.5	127.1	15	0		142.1	686.9	
17	Pearl Highlands	22677	686	88.5	61.0	35	0		96.0	782.9	
18	Pearlridge	26347	3670	88.5	184.8	20	0		204.8	987.7	
19	Aloha Stadium	28529	2182	88.5	123.1	15	0		138.1	1125.8	
20	Ala Liliko'i	32519	3990	88.5	198.1	20	0		218.1	1343.9	
21	Middle Street	35921	3402	88.5	173.7	15	0		188.7	1532.6	
22	Kalihi	36674	753	88.5	63.8	20	0		93.8	1626.4	
23	Kapalama	37923	1250	88.5	84.4	15	0		99.4	1725.7	
24	Iwilei	38704	780	88.5	64.9	15	0		79.9	1805.7	
25	Chinatown	39289	585	88.5	56.8	15	0		71.8	1877.5	
26	Downtown	40020	732	88.5	62.9	25	0		87.9	1965.4	
27	Civic Center	40700	680	88.5	60.7	20	0		80.7	2046.1	
28	Kaka'ako	41457	757	88.5	64.0	15	0		79.0	2125.1	
29	Ala Moana Center	42702	1245	88.5	84.2	0	0		84.2	2209.3	
30	**Total**	**30815**	**metres**	**50.2**	**km/h av speed**		**36.8**	**mins total time**			
31	Turnback Time with forward cross-over			15	seconds	slow speed over approach special work					
32	Terminal Dwell			0	seconds	included in layover					
33	Layover Time			221	seconds		10	% of travel time to be split between terminals			
34	**Round Trip Time**			**78**	**mins**	(should be adjusted to multiple of train headway)					

Line 30 shows an average speed (without terminal dwells) of 50.2 km/h (31.2 mph). This is higher than normal for a metro line with average station spacing of 5320 feet, anything over 28-30 mph is suspicious. Consequently the model was run with more realistic parameters of 49.7 mph maximum speed and initial acceleration and service braking at 2.46 mphps. The calculated round trip time is 82

minutes.[8] The results of these two runs are compared together with the City provided travel times in the following table.

Travel Times (seconds) without dwell times	City Provided	TCL Model	
		Full	Realistic
East Kapolei			
UH West O'ahu	99	98	115
Ho'opili	100	95	110
West Loch	143	143	166
Waipahu Transit Center	112	119	139
Leeward CC	122	127	148
Pearl Highlands	64	61	71
Pearlridge	182	185	216
Aloha Stadium	123	123	144
Ala Liliko'i	206	198	231
Middle Street	198	174	203
Kalihi	63	64	74
Kapalama	77	84	98
Iwilei	66	65	75
Chinatown	64	57	66
Downtown	82	63	73
Civic Center	56	61	71
Kaka'ako	72	64	74
Ala Moana Center	119[9]	84	98
Total One-Way Minutes	**32.5**	**31.1**	**36.2**
Round Trip Time[10] Min	**78**	**75**	**84**

The *City Provided* and *Full Performance* times are very similar, although there are differences that should be investigated but are beyond the scope of this two-day review. The recommended *Realistic Performance* travel times are slightly longer. At full performance the round trip times calculated are less than the City estimate. This simply reflects good practise in not leaving six million dollar trains sitting idle at terminals more than necessary for dwells, staff end-changing and recovery time.

Turn back Capacity

Provided that the terminal crossovers are close to the station any train control system will be able to support headways down to at least two minutes, well within the projected closest headways. Consequently the TCRP 13 or TCRP 100 detailed analysis of the spot report is unnecessary and is not reviewed.

Maximum Line Capacity

The maximum line capacity is primarily a function of the vehicle and train control system selected. As these are not yet determined the detailed analysis of the spot report is pointless. A simple calculation will suffice to give a range. Three-car trains with a capacity of 504 to 630 passengers, combined with a headway of 120 seconds (conventional signalling) to 100 seconds (moving block) produces a range of 15,000 to 23,000[11] passengers per peak hour direction.

Calculated Vehicle Fleet Size

The vehicle fleet size is a simple arithmetic calculation involving round trip time, ridership, car capacity, train length, loading diversity and the spare ratio. The third module of the TCL Train Performance Model calculates this as shown below.

Round Trip Time	78 mins		Full Performance (Not adjusted to multiple of train headway)
Peak Point Demand	6200	ppphd	peak point (can be 15 minute-peak times 4)
Diversity Factor	85	%	reflects cars and trains cannot load evenly over full peak hour
Car Capacity	168		loading level — 50 seats; 3.4 passengers/m^2
Train	2	car(s)	35m 2 car set
Peak Headway	166	seconds	do not round to clock headways
Peak Cars	58	cars	rounded up to multiples of train length

8 Round trip time should be adjusted to a multiple of train headway—not done here
9 Higher value is probably due to reduced approach speed — which is added into the TCL Model layover time
10 with station dwells as per this memo
11 The National Fire Prevention Association 130 requirements for station exiting needs checking to ensure this higher volume can be supported by the station designs.

Spare Ratio[12]	15	%	typical of new rail systems
Fleet Requirement	**68**	**cars**	

The diversity factor is reduced from the 0.80 recommended in TCRP 13 or TCRP 100 to 0.85, as passengers spread more evenly along platforms with short 2-car trains. (A closer examination might reduce this further to 0.90.)

The spare ratio has been reduced from 20% to 15%. All modern rail cars are approaching *mean times between service failures* in excess of 100,000 miles—an order or magnitude better than older generations. Combined with on-demand maintenance and line replaceable units, trains spend appreciably less time in maintenance. Many new systems use a spares ratio of 10–12% and some as low as 8%. It is uneconomic to have excessive rolling stock. Counteracting the higher spares ratio often needed in the first few years of operation, due to infant mortality and maintenance staff learning curves, is that the fleet is based on 2030 ridership and there will be ample spares during the early years. The vehicle fleet size under different loading criteria and performance is tabulated below:

FLEET SIZE	Full Performance		Realistic Performance	
Ridership ppphd	6200	5600[13]	6200	5600
60 foot cars 3.4 sq. ft. / standee	**68 cars**	**60 cars**	**72 cars**	**66 cars**
66 foot cars 2.7 sq. ft. / standee	**54 cars**	**50 cars**	**58 cars**	**52 cars**

Short-turn

Ridership drop-off at the Ewa end of the line would allow a short-turn of one train in three at Leeward Community College. This would reduce fleet size by approximately 7%[14], but presents some inconvenience for passengers and makes operations more complex. The fleet size would reduce by 4.

Reducing the Fleet Size

The following table examines other ways to reduce fleet size, followed by a discussion on other reductions by introducing a short-turn or by staged vehicle procurement. The base is a fleet of 68 60-foot cars with 50 seats, 3.4 sq. ft. / standees, and full performance from the above table.

	Method	Reduction	Net
A	As discussed in this memo the Honolulu peak-within-the peak should be less than on high volume systems particularly now that the uniform 9 to 5 workday is disappearing. Here this factor is changed from 0.8 to 0.9 but needs confirming with ridership data.	6	62
B	Loading diversity will be small for 120-foot long trains. This factor could be adjusted further from 0.85 to 0.90.	4	64
C	A slightly longer train — combined with the good stopping accuracy of many current ATO train control systems — will reduce fleet size proportionately, here for a 66 foot car allowing a 3-car train to fit platform. (with 50 seats and generous 3.4 sq. ft. / standee.)	8	60
D	Adjusting the standing space from 3.4 sq. ft. / standee to the normal North American standard of 2.7 sq. ft. / standee. (Only applies briefly during the peak-within-the peak)	12	56
E	Substituting jump seats for ten fixed seats. This provides the same number of seats off-peak with 12 extra standees in the peak.	4	64
F	Train attendant setback at the Ala Moana terminal (or driverless trains with roving attendants) would allow a reduction in layover time (both terminals combined) from the 10% allowed to 7%, still adequate for recovery purposes.	2	66
G	The above described short-turn at Leeward Community College	4	64

[12] This ratio supports one “ready” train at all times, two at most times.
[13] Reduced hourly volume to reflect lower peak-within-the-peak.
[14] 6.6 % actual calculation for Realistic Performance with 60 foot cars and 3.4 sq. ft. per standing passenger

Most of the above strategies can be combined, but, as the model rounds the fleet size up in increments of two, the result will vary slightly from a simple addition.

Staged Vehicle Procurement

Buying an initial fleet for the estimated 2030 ridership has the advantages of uniformity and economy of scale. However the fleet would be underutilized in the early years. An alternate is a two-stage process buying a fleet sufficient for the first ten years or so, followed by a second batch. The downside is that the second batch will not be identical—there will be technical advancements over ten years; and there could be a price premium for the smaller second order. These disadvantages can be mitigated in the first procurement by favoring, in the specification and bid evaluation, an established design used in a large fleet elsewhere, so making it likely that the vehicle will be in production for a long period—with the possible to add-on to a future larger order from other systems. The second tranch need not be identical—other than train-line compatible, the same width and a similar length. The penalty for additional maintenance training and stocking spares for this batch would be minor.

Future plans are for 3-car trains. Although it is possible to insert a middle car and so convert the original fleet from two to three-car trains this is easier said than done. The new middle car will have a reduced life span, likely being retired when the "end" cars are life expired, possibly mitigated by adding this car during a mid-life rebuild of the original fleet. There will also be costs in ensuring the middle cars are compatible with the potentially obsolete sub-systems of the original fleet. On the positive side the second batch of cars could be acquired as three-car trains and would be able to run inter-mixed[15] with the original 2-car trains—which would be retired at 30 years and replaced with 3-car trains.

Data on ridership build-up would allow the initial fleet size in a staged procurement to be estimated. Without this, a best estimate is that the 68-car fleet could be an initial batch of 48 with an add-on of 20 cars—or more—to carry the fleet, say to 2035 or 2040.

Summary

The spot report has applied the complex math in this writer's *Rail Transit Capacity Report (as replicated in TCRP 100)* without common sense or a good understanding of rapid transit operations. The dwell average of 20 seconds, distributed among stations according to use, is sufficient. The travel times are optimistic and should be reviewed. Peak 15-minute demand should be determined specifically for Honolulu rather than using the TCRP 13 recommendation, which is for higher volume heavy rail systems. The diversity factor should be adjusted for the short trains and the vehicle spares ratio reduced to reflect current experience with new, modular, AC propulsion rail cars. Consideration should be given to a range in the vehicle length specification to give more bidding flexibility and so potentially lowering the price.

A variety of strategies make it possible to reduce the fleet size from the estimated 68 into the middle forties, with further reductions possible with Staged Vehicle Procurement.

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[15] Running trains of different lengths is regarded as poor practice but works fine in other cities, for example Vancouver where original 160-foot long trains run throughout the day mixed with 115 and 230 foot long trains of the new Mark II cars. The long trains are staged to best meet the peak-within-the peak demand.