observations indicate that entry speed has a considerable effect on deceleration rates for both trucks and recreational vehicles.

We commend Linzer, Roess, and McShane for their pragmatic approach to revising equivalency factors so that engineers can account for the changes that have occurred during the past two decades in vehicle performance and in the composition of the mixed traffic stream. The authors' assumptions concerning the performance of typical vehicles appear to be reasonable, and their use of previously accepted research results is innovative.

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Street Capacity for Buses in the Honolulu Central Business District

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A bus demonstration conducted in January 1978 in Honolulu is reported. The purpose of the demonstration was to determine the bus capacity of Hotel Street, the major bus corridor in the Honolulu central business district, under existing traffic and roadway conditions. Although buses were metered into both directions of Hotel Street at flow rates of 60, 120, 138, and 150 buses/h, only 100 to 120 buses/h could actually enter the system. Restrictions within the system further reduced bus flow. Major bottlenecks are identified, and the resulting impacts on vehicles, pedestrians, and the environment are assessed. It is concluded that directional bus capacity on Hotel Street was 95-100 buses/h at average speeds that ranged from 3 to 5 km/h (2 to 3 mph).

A major transit trip generator in Honolulu is the central business district (CBD), which encompasses an area of about 0.5 km^2 (0.2 mile^2). This generator is served by 22 of the 39 available scheduled bus routes. The primary east-west roadway used by bus routes through the CBD is Hotel Street, which is approximately 0.8 km (0.5 mile) long and is intersected by nine one-way side streets, seven of which are signalized (see Figure 1). There are 10 bus stops along Hotel Street, 6 on the north side and 4 on the south side. Fifteen of the 22 bus routes use some section of Hotel Street, and 7 bus routes intersect Hotel Street. During the off-peak period, Hotel Street handles between 50 and 56 buses/h in each direction. This increases to 72-80 buses/h during the morning peak period.

Hotel Street is a two-lane collector approximately 11 m (36 ft) wide that serves mixed traffic. At some intersections, the roadway flares to 12 m (40 ft), which allows both left and through movements in one lane. Although there are no bus bays on Hotel Street, it is not unusual for vehicles to pass one or two buses loading or unloading at a bus stop.

The land use adjacent to Hotel Street is zoned B-4, CBD, which is intended to denote the metropolitan center for financial, commercial, government, professional, and cultural activities. Also in the surrounding area are the state capitol, city hall, government offices, and major tourist attractions of historical interest.

In terms of transit, the city and county of Honolulu currently maintains a fleet of 350 buses. The system is wholly owned by the city and county of Honolulu, but its operation is contracted to a private carrier—MTL. This bus system is well received in the community. Although the urban portion of Honolulu ranks forty-third in population, bus ridership is the thirteenth highest in the country. Ridership figures for 1977 indicate a total ridership of 66.6 million, composed of 47.5 million paying passengers, 11.8 million transfers, and 7.3 million free senior citizen passengers.

PURPOSE OF THE STUDY

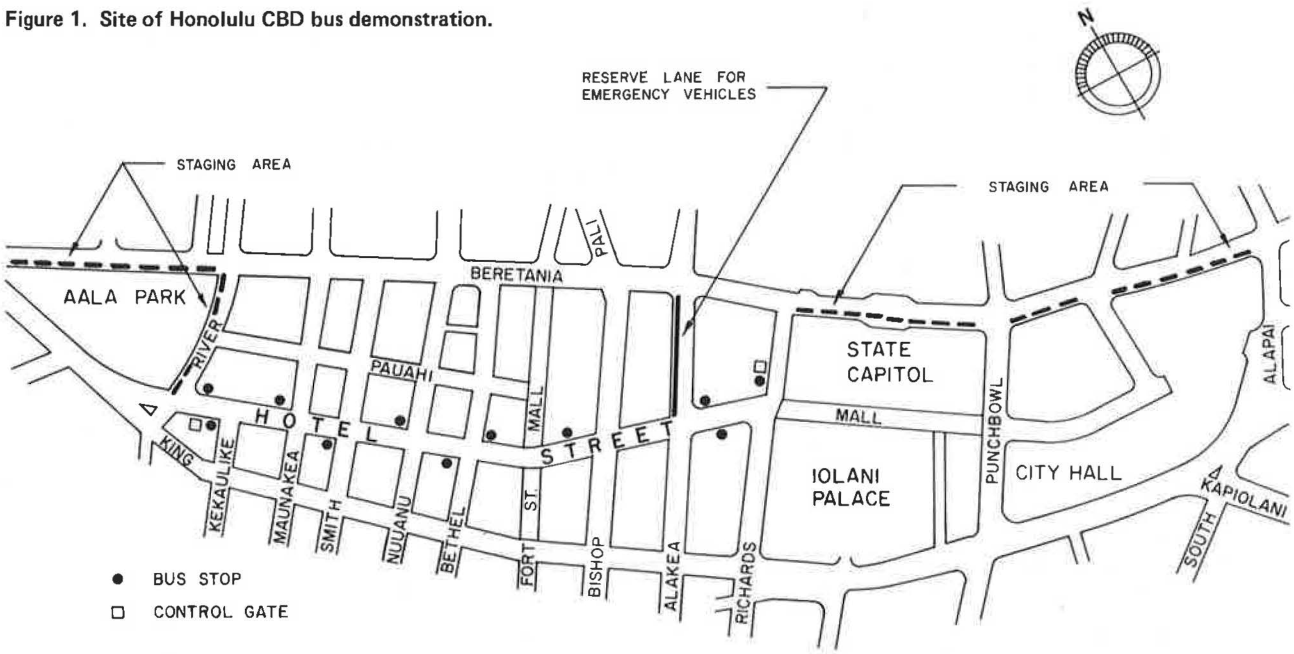
On January 20, 1978, the Honolulu Department of Transportation Services (DTS) conducted a study that involved the regulation of the major bus flow through the Honolulu CBD. The purpose of the Hotel Street bus demonstration was to determine the maximum bus volume Hotel Street can carry under present roadway and traffic conditions. The existing literature (1, 2, 3) indicates a wide range of values. The study also attempted to identify major bottlenecks and to quantify the resulting impacts on vehicles, pedestrians, and the environment.

The bus study was conducted under two constraints. First, the study occurred on Friday between 10:00 a.m. and 12:30 p.m., during the normal work periods of the department staff. Because of this, the observed traffic measures do not reflect peak-hour traffic conditions that occur on Hotel Street. Second, efforts were made to maintain current patterns of automobile use and bus patronage. Traffic signal timings and bus routes were not changed for the study.

PROCEDURE

During the bus demonstration, the flow of buses into Hotel Street was controlled in both directions. During various phases of the 10:00 a.m. to 12:30 p.m. test period, buses were scheduled to enter both ends of Hotel Street

Figure 1. Site of Honolulu CBD bus demonstration.



at predetermined flow rates.

Given a supply of 60 test buses and an off-peak directional volume of approximately 55 vehicles/h, bus flow rates greater than 120 buses/h in each direction could not be sustained for very long. This factor, plus the constraint of minimizing traffic impacts when possible, resulted in each of the four test periods lasting no more than 30 min.

Four bus flow rates, or headways, were used in the study. From 10:00 to 10:30 a.m., buses that entered Hotel Street had an initial headway of 60 s, which corresponds to an equivalent flow of 60 buses/h. This approximated the existing off-peak bus volume even though current bus traffic does not enter Hotel Street with uniform headways. Between 10:35 and 11:00 a.m., buses were scheduled to enter at a rate of 120 buses/h (30-s headway). Between 11:05 and 11:35 a.m., buses were scheduled to enter at a rate of 138 buses/h (26-s headway) and, between 12:00 noon and 12:30 p.m., buses were scheduled to enter every 24 s or at a flow rate of 150 buses/h.

To determine the bus capacity of Hotel Street, the controlling intersection with the minimum service volume was identified for each direction. The maximum bus volume passing this intersection during the 30-, 26-, and 24-s-headway test periods was defined as the capacity on Hotel Street for the respective direction.

To regulate flow rates entering both ends of the system, control gates were set up eastbound on Hotel at River and westbound on Richards at Hotel (Figure 1). The 60 additional test buses used to maintain the desired constant headways were stored in staging areas near the control gates and released into the system when they were needed.

Two scheduled bus routes entered and departed from Hotel Street at nonregulated points. These buses were monitored while they were on Hotel Street.

To maintain the actual pattern of bus patronage, boarding and alighting times of regularly scheduled buses were not controlled. However, test buses were required to stop for 15 s at each bus stop to simulate passenger boarding and alighting. Current policy allows the first two buses at a bus stop to load or unload their passengers and requires the following buses in the queue to wait until they reach the first two positions. This policy was maintained during the bus study.

While the experiment was being conducted, traffic, pedestrian, and environmental data were collected to assess transportation impacts. More than 150 persons from various city and state agencies were involved in the experiment. Buses were controlled and bus movements past each bus stop and intersection were monitored by 109 persons, including 60 test bus drivers. To assess impacts on automobile movements, 23 persons collected data for various traffic studies. Six persons recorded pedestrian movements at key sites crossing Hotel Street. To assess environmental impacts, four persons recorded noise levels and another four recorded air pollution levels. Six persons photographed the demonstration.

Before conducting the Hotel Street bus demonstration, DTS met with a number of local agencies to ensure the safety of the public during the study period, and an emergency plan was established.

FINDINGS

A brief discussion of the findings of the study is presented here. A more detailed discussion, with photographs, is available elsewhere (4).

Bus Movements

During the test periods, bus travel times through the system could be categorized into three phases. The first was the lag phase, which usually occurred during the beginning of the test period. This phase is characterized by relatively short travel times through the system. The buses at the beginning of the lag phase seemed to have almost no effect on following buses. The lag phase was followed by a transient phase in which travel times significantly increased during a relatively short period of time. A stabilized phase then followed in which travel times fluctuated about a relatively high value.

An upper limit of 16 min was observed during the test periods in both the eastbound and westbound directions. This upper limit is associated with the capacity at the inflow control gates (although 120, 138, and 150 buses/h was attempted at the control gates, only about 120 buses/h and 100-115 buses/h passed through the eastbound and westbound control gates, respectively) and the traffic conditions downstream of the exiting gate (large bus volumes were not maintained past the control gates).

Because of these characteristics, bus volumes, speeds, and dwell times were analyzed during fixed time periods that began about 10 min after the start of each test period

Table 1. Bus volume eastbound.

		Location								
Analysis Period	Item	Kekaulike	Maunakea	Smith	Nuuanu	Bethel	Fort Street Mall	Bishop	Alakea	Richards
10:00-10:30 a.m.	Number of buses[a]	28	28	28	28	30	30	30	28	28
	Time (min)	27.90	27.13	27.16	27.68	27.32	27.44	26.21	27.27	26.35
	Volume (buses/h)	60	62	62	61	66	66	69	62	64
10:45-11:00 a.m.	Number of buses[a]	27	27	27	27	28	28	28	26	26
	Time (min)	13.67	14.25	14.90	18.61	19.41	20.98	20.26	20.61	20.20
	Volume (buses/h)	119	114	109	87	87	80	83	76	77
11:15-11:30 a.m.	Number of buses[a]	29	29	29	29	30	30	30	29	29
	Time (min)	14.24	17.77	17.79	16.33	16.25	16.86	17.21	17.98	17.97
	Volume (buses/h)	122	98	98	107	111	107	104	97	97
12:10-12:24 p.m.	Number of buses[a]	28	28	28	28	29	29	29	28	28
	Time (min)	13.72	15.47	15.93	16.37	15.95	15.57	17.15	16.84	17.16
	Volume (buses/h)	122	109	105	103	109	112	101	100	98

[a] A difference in the number of buses results partially from buses entering and departing the system at points other than the control points.

Table 2. Bus volume westbound.

		Location									
Analysis Period	Item	Richards	Alakea	Bishop	Fort Street Mall	Bethel	Nuuanu	Smith	Maunakea	Kekaulike	River
10:00-10:30 a.m.	Number of buses[a]	28	28	31	31	31	31	31	31	31	31
	Time (min)	27.95	27.50	28.47	28.23	27.38	27.53	27.77	27.53	27.64	27.93
	Volume (buses/h)	60	61	65	66	68	68	67	68	67	67
10:45-11:00 a.m.	Number of buses[a]	25	25	27	27	27	27	27	27	27	27
	Time (min)	13.43	14.07	15.93	17.07	16.68	16.81	17.01	15.68	15.62	15.77
	Volume (buses/h)	112	107	102	95	97	96	95	103	104	103
11:15-11:30 a.m.	Number of buses[a]	26	26	27	27	27	27	27	27	27	27
	Time (min)	15.88	16.50	16.71	17.43	16.68	16.18	15.69	15.87	15.79	15.94
	Volume (buses/h)	98	95	97	93	97	100	103	102	103	102
12:10-12:24 p.m.	Number of buses[a]	21	21	22	22	22	22	22	22	6[b]	22
	Time (min)	11.08	14.03	15.22	14.46	12.33	12.62	12.21	12.30	3.13[b]	11.90
	Volume (buses/h)	114	90	87	91	107	105	108	107	115[b]	111

[a] A difference in the number of buses results partially from buses entering and departing the system at points other than the control points. [b] Incomplete data.

Table 3. Bus speed eastbound.

	Bus Speed (km/h)						
Analysis Period	Kekaulike-Smith	Smith-Nuuanu	Nuuanu-Bethel	Bethel-Fort Street Mall	Fort Street Mall-Bishop	Bishop-Richards	System (without entry delay)
10:00-10:30 a.m.	10.8	15.6	4.8	20.1	13.3	11.7	9.3
10:45-11:00 a.m.	7.9	4.8	2.6	4.5	4.0	9.2	4.7
11:15-11:30 a.m.	2.4	2.4	2.4	4.0	4.0	7.7	3.2
12:10-12:24 p.m.	3.0	2.3	2.4	5.8	4.7	7.6	3.5

Note: 1 km = 0.62 mile.

Table 4. Bus speed westbound.

	Bus Speed (km/h)								
Analysis Period	Richards-Alakea	Alakea-Bishop	Bishop-Fort Street Mall	Fort Street Mall-Bethel	Bethel-Nuuanu	Nuuanu-Smith	Smith-Maunakea	Maunakea-Kekaulike	Kekaulike River	System (without entry delay)
10:00-10:30 a.m.	10.3	9.7	9.0	6.9	22.4	13.2	16.6	15.1	6.8	8.5
10:45-11:00 a.m.	1.9	8.7	7.6	3.5	12.9	7.2	11.9	9.8	6.8	4.0
11:15-11:30 a.m.	1.8	3.7	5.3	6.1	18.5	8.7	13.0	15.3	10.0	4.2
12:10-12:24 p.m.	1.8	2.1	4.2	7.4	22.2	9.8	13.5	9.7	7.7	3.7

Note: 1 km = 0.62 mile.

(corresponding roughly to the stabilized phase). These time periods are defined as the analysis periods.

Bus volumes were determined by dividing the number of buses by the time interval between the first and last bus of each analysis period. Bus volumes in the eastbound direction were calculated for the following intersections on Hotel Street (see Table 1): Kekaulike, Maunakea, Smith, Nuuanu, Bethel, Fort Street Mall, Bishop, Alakea, and Richards. It should be noted that one or two regularly scheduled buses entered Hotel Street at Nuuanu during the analysis periods and were considered in the computations.

There was no problem, with respect to eastbound bus volumes, with a flow rate of 60 buses/h. However, when flow rates of 120, 138, and 150 buses/h were attempted through the control gate, only about 120 buses/h could actually pass this intersection. Flow rates through the other intersections were lower than those past the control gate.

Bus volumes dropped immediately as buses approached Smith, where a nearside bus stop is located. Bus volumes then decreased again at Bishop, Alakea, and Richards. The shortest green time—32 s—occurred at Bishop; a major midblock bus stop is located between Alakea and Richards.

Bus volumes in the westbound direction during each test period were calculated at the following locations (see Table 2): Richards, Alakea, Bishop, Fort Street Mall, Bethel, Nuuanu, Smith, Maunakea, Kekaulike, and River. One regularly scheduled bus route entered Hotel Street at Alakea, thus bypassing the control point. This resulted in an increase of as much as 7 buses/h in the number of buses in the system west of the Alakea intersection in each test period. Again, there was no problem in the westbound direction with a flow rate of 60 buses/h.

The maximum service rate at the Richards control gate ranged between 100 and 115 buses/h. The first bottleneck occurred at Alakea, the location of a nearside bus stop. Past Bishop (the intersection with the shortest green time) and Fort Street Mall (location of a major midblock bus stop), bus volumes decreased further. Bus volumes increased past Fort Street Mall through River.

Average bus speeds (space mean speed) were calculated for links (between intersections) and the system (from the control gate to the end of the system). Delays that resulted when a bus was unable to leave the control gate on schedule were not included in the analysis. All other delays were included in calculations of travel time and speed.

In the eastbound direction, system bus speeds from the control gate to Richards ranged from 3.2 to 4.7 km/h (2.0 to 2.9 mph) during the large flow rates, as given in Table 3. This is a decrease from 9.3 km/h (5.8 mph) during the 60-buses/h analysis period. Average link speeds decreased as buses approached Bethel and increased as buses left Bethel. A major nearside bus stop is located at this intersection.

Table 5. Selected performance characteristics of buses at bus stops.

Bus Stop	Test Flow Rate (buses/h)	Avg Link Speed (km/h)	Avg Bus Volume (buses/h)	Avg Dwell Time (s)	Upstream Green Time (s)
Near side					
Smith	120	7.9	109	12	48
Bethel	120	2.6	87	23	48
Alakea	120	1.9	107	11	40
Bethel	120	3.5	97	15	48
River	120	6.8	103	16	44
Smith	138	2.4	98	13	48
Bethel	138	2.4	111	21	48
Alakea	138	1.8	95	11	40
Bethel	138	6.1	97	13	48
River	138	10.0	102	16	44
Smith	150	2.9	105	12	48
Bethel	150	2.4	109	22	48
Alakea	150	1.8	90	11	40
Bethel	150	7.4	107	14	48
River	150	7.7	111	-[a]	44
Average	150	4.5	102	15.0	
Midblock					
Alakea	120	9.2	77	23	-[b]
Union	120	7.6	95	27	52
Alakea	138	7.7	97	19	-[b]
Union	138	5.3	93	25	52
Alakea	150	7.6	98	21	-[b]
Union	150	4.2	91	32	52
Average		6.9	92	24.5	
Far side					
Nuuanu	120	7.2	95	12	48
Maunakea	120	9.8	104	13	-[b]
Nuuanu	138	8.7	103	10	48
Maunakea	138	15.3	103	12	-[b]
Nuuanu	150	9.8	108	9	48
Maunakea	150	9.7	115	13	-[b]
Average		10.1	105	11.5	

Note: 1 km = 0.62 mile.
[a]Not available. [b]No traffic signal.

Table 6. Composition of traffic eastbound.

Site	Type of Vehicle	Composition by Test Period (vehicles/h): 60 Buses per Hour[a] Number	Percent	120 Buses per Hour[a] Number	Percent	138 Buses per Hour[a] Number	Percent	150 Buses per Hour[a] Number	Percent
Maunakea	Bus	60	40	118	46	123	58	128	50
	Commercial	14	10	22	8	9	4	16	6
	Automobile or taxi	74	50	120	46	81	38	112	44
	Total	148		260		213		256	
Fort Street Mall	Bus	65	23	96	38	110	39	110	41
	Commercial	36	13	28	11	29	10	18	7
	Automobile or taxi	182	64	126	51	144	51	142	52
	Total	283		250		283		270	
Alakea	Bus	65	18	86	22	101	22	96	25
	Commercial	50	14	38	10	19	4	26	7
	Automobile or taxi	254	68	272	68	343	74	254	68
	Total	369		396		463		376	

[a]Represents the bus flow attempted at the control gates and is used solely to identify a specific time or test period. As stated earlier, the control gates could handle only 100-120 buses/h.

Table 7. Composition of traffic westbound.

Site	Type of Vehicle	Composition by Test Period (vehicles/h): 60 Buses per Hour[a] Number	60 Buses per Hour[a] Percent	120 Buses per Hour[a] Number	120 Buses per Hour[a] Percent	138 Buses per Hour[a] Number	138 Buses per Hour[a] Percent	150 Buses per Hour[a] Number	150 Buses per Hour[a] Percent
Alakea	Bus	70	23	120	38	96	34	102	39
	Commercial	38	13	34	11	12	4	6	2
	Automobile or taxi	190	64	166	51	174	62	156	59
	Total	298		320		280		264	
Fort Street Mall	Bus	65	24	106	34	103	36	82	34
	Commercial	26	10	34	11	34	12	17	7
	Automobile or taxi	182	66	173	55	149	52	142	59
	Total	273		313		286		241	
Maunakea	Bus	67	20	103	39	108	29	111	42
	Commercial	48	14	31	12	42	11	15	6
	Automobile or taxi	221	66	132	49	219	60	138	52
	Total	336		266		369		264	

[a]Represents the bus flow attempted at the control gates and is used solely to identify a specific time or test period. As stated earlier, the control gates could handle only 100-120 buses/h.

Table 8. Occurrences of bus noise levels in excess of the 92-dB(A) state standard.

Time Period	Fort Street Mall North: Sound Level [dB(A)]	North: No. of Exceedences	Fort Street Mall South: Sound Level [dB(A)]	South: No. of Exceedences	Bishop Street (north): Sound Level [dB(A)]	Bishop Street (north): No. of Exceedences	Bethel Street (south): Sound Level [dB(A)]	Bethel Street (south): No. of Exceedences
9:30-10:00 a.m.	89	0	90	0	91	0	-[a]	-[a]
10:00-10:30 a.m.	80	0	89	0	92	0	89	0
10:30-11:00 a.m.	-[a]	-[a]	90	0	93	1	86	0
11:00-11:30 a.m.	89	0	86	0	94	1	86	0
11:30 a.m.-12:00 n.	-[a]	-[a]	90	0	90	0	87	0
12:00 n.-12:30 p.m.	92	0	89	0	94	2	89	0

[a]Not available.

In the westbound direction, bus speeds through the system ranged from 3.7 to 4.2 km/h (2.3 to 2.6 mph) during the large flow rates, as given in Table 4. This is a decrease from 8.5 km/h (5.3 mph) during the 60-buses/h analysis period. Average link speeds were low at the beginning of the system and peaked at the Bethel-Nuuanu link.

Bus dwell times were averaged for each of the nine bus stops located at the test site (three on the south side of Hotel Street and six on the north side). Average dwell times are presented for regularly scheduled buses and test buses during the four analysis periods.

Only three eastbound bus stops were involved in the study of bus dwell time: (a) Hotel at Smith, (b) Hotel at Bethel, and (c) Hotel at Alakea. There are two major bus stops in the eastbound direction: Bethel and Alakea. During large flow rates, dwell time averaged between 21 and 23 s at Bethel, a nearside bus stop, and between 19 and 23 s at Alakea, a midblock bus stop. At Smith, a minor nearside bus stop, dwell times averaged 12 to 13 s during large flow rates.

Six westbound bus stops were involved in the study of dwell time: (a) Hotel at Alakea, (b) Hotel at Union Mall, (c) Hotel at Bethel, (d) Hotel at Nuuanu, (e) Hotel at Maunakea, and (f) Hotel at River. Union Mall bus stop is the major bus stop in the westbound direction. Average dwell time at this midblock bus stop ranged between 25 and 32 s. Dwell times at other nearside bus stops—Alakea, Bethel, and River—and at farside bus stops—Nuuanu and Maunakea—averaged less than 17 s during the analysis periods.

During the bus demonstration, it was observed that bus stops were a major bottleneck. Table 5 gives selected performance characteristics of buses during the last three analysis periods. These data are categorized for nearside, midblock, and farside bus stops.

The data indicate that, of the three types of bus stops, nearside bus stops at signalized intersections had the greatest adverse impact on bus speeds. The average link speed with nearside bus stops was 4.5 km/h (2.8 mph) compared with 6.9 and 10.1 km/h (4.3 and 6.3 mph) on links with midblock and farside bus stops, respectively.

When links with bus stops are considered, it appears that average dwell times or green times did not have a significant impact on average link speed. There was very little correlation between average link speed and average dwell time ($r = 0.1$) or green time ($r = 0.3$).

Bus volumes on links with nearside bus stops ranged from 87 to 111 buses/h and averaged 102 buses/h. On midblock links, bus volumes ranged from 77 to 98 buses/h and averaged 92 buses/h. Links with farside bus stops had bus volumes that ranged from 95 to 115 buses/h and averaged 105 buses/h.

Although the range and average bus volume on links with nearside bus stops were similar to those on links with farside bus stops, average link speed on links with nearside stops was 125 percent lower.

Average link speeds were 54 percent lower on links with nearside bus stops than on links with midblock bus stops, but average bus volumes were 10 buses/h lower on links with midblock bus stops. To determine whether this lower bus volume was related to higher link speeds, selected characteristics of bus performance were tabulated for links with nearside bus stops that had bus volumes within the same range as the links with midblock bus stops. The table below, which gives this information, uses a bus volume of 77 to 98 buses/h and indicates that average link speeds were still lower (by 126 percent) on links with nearside bus stops (1 km = 0.62 mile):

Bus Stop	Avg Link Speed (km/h)	Avg Bus Volume (buses/h)	Avg Dwell Time (s)
Bethel	2.6	87	23
Alakea	1.8	90	11
Alakea	1.8	95	11
Bethel	6.1	97	13
Bethel	3.5	97	15
Smith	2.4	98	13
Average	3.1	94	14.3

Since other variables that could have affected bus speeds, such as signal timing or block length, were not analyzed, the conclusions presented in this section require further analysis.

Other Vehicle Movements

The following types of vehicle surveys were conducted during the bus demonstration: (a) 24-h traffic count, (b) queue length on side streets, (c) traffic composition, and (d) speed and delay.

Twenty-four-hour traffic counts at selected sites along Hotel Street indicated no significant differences in traffic volumes during the 24-h period and the 2.5-h test period for the test day and other previous days.

Traffic queue counts for four side streets were obtained during the experiment. Queues that approached the intersections at the end of the red phase were counted at Nuuanu, Bethel, Bishop, and Alakea. Nuuanu was the only surveyed roadway that reported an occasional fully loaded signal cycle during the study.

Surveys of traffic composition were taken at three sites for both eastbound and westbound directions along Hotel Street. Surveyors located at these sites recorded the number of city buses, other buses, commercial vehicles, automobiles, and taxis in 5-min intervals. Motorcycles and bicycles were not included in the totals.

Traffic composition was determined for three sites located in the eastbound direction of Hotel Street just west of (a) Maunakea, (b) Fort Street Mall, and (c) Alakea (see Table 6). Total traffic counts, from 10:00 a.m. to 12:30 p.m, for city buses, commercial vehicles, and automobiles and taxis ranged from 976 vehicles at Alakea to 551 vehicles at Maunakea. At Fort Street Mall, 679 vehicles were recorded. During this period, the largest category of vehicles recorded was automobiles and taxis, which made up between 48 and 69 percent of the vehicles recorded at the three sites. This was followed by city buses (22 to 43 percent) and commercial vehicles (9 to 11 percent).

Traffic composition was also determined for the three sites located in the westbound direction of Hotel Street just west of (a) Alakea, (b) Fort Street Mall, and (c) Maunakea (see Table 7). During the study period, the totals of city buses, commercial vehicles, and automobiles and taxis at these sites were about the same. Vehicle counts ranged from 701 to 757 vehicles. During this period, automobiles and taxis made up 59 to 60 percent of the recorded traffic, the largest of the three categories at the three sites. This was followed by city buses (30 to 32 percent) and commercial vehicles (9 to 10 percent).

A total of 35 speed and delay runs were made in the study area from 10:00 a.m. to 12:30 p.m. Each of the five roadways surveyed—Hotel, King, Beretania, Bishop, and Alakea—were divided into three links of reasonably uniform physical and traffic characteristics. Speed and percentage of travel time attributable to delays were calculated for each link of each test run. Delays resulted from traffic signals, traffic backups, pedestrians, buses, and turning vehicles.

Six automobile runs were made on Hotel Street in the eastbound direction. The average system speed during the 60-buses/h analysis period was 10.4 km/h (6.4 mph). During the periods of greater bus flows, system automobile speeds were 7.8 km/h (4.8 mph), 6.1 km/h (3.8 mph), and 6.6 km/h (4.1 mph), respectively.

Four automobile speed and delay runs were made on Hotel Street in the westbound direction. The average system speed during the 60-buses/h analysis period was 17.7 km/h (11.0 mph). During the periods of greater bus flows, system automobile speeds were 10.3 km/h (6.2 mph), 7.0 km/h (4.3 mph), and 7.2 km/h (4.5 mph), respectively.

Pedestrian Movements

During the 2.5-h test period, a total of 12 939 pedestrians crossed Hotel Street at three intersections: Bishop, Bethel, and Fort Street Mall. During the pedestrian peak-hour period, between 11:30 a.m. and 12:30 p.m., 6727 pedestrians crossed Hotel Street at the three intersections.

The heaviest pedestrian traffic occurred at the intersection of Hotel Street and Fort Street Mall. A total of 6394 pedestrians used this intersection during the test period, and the average flow rate was 2558 pedestrians/h. The 15-min pedestrian counts ranged from a low of 459 pedestrians during the earlier portion of the test period (or a flow rate of 1836 pedestrians/h) to a high of 1014 pedestrians during the latter portion of the test period (or a flow rate of 4056 pedestrians/h).

Environmental Impacts

Existing standards for the state of Hawaii were used to evaluate the results of noise and air pollution measurements taken during the experiment.

The noise level of heavy vehicles on any traffic way with a posted speed limit of 56 km/h (35 mph) or less is not to exceed 92 dB(A) [fast meter response measured at 6 m (20 ft) from the centerline] during daytime hours (6:00 a.m to 6:00 p.m.) (5). Four noise analyzers monitored noise levels 9 m (30 ft) from the center of Hotel Street.

All noise levels recorded at Fort Street Mall (north and south) and Bethel (south) were within the standard. However, as given in Table 8, noise levels at Bishop exceeded 92 dB(A) four times during the 3-h test period. The maximum noise level recorded was 94 dB(A). The high noise level at this site may be attributable to the fact that the noise meter was located within 6 m (20 ft) of the noise source and approximately 1.5 m (5 ft) of a concrete structure, an effective sound-reflecting surface.

Average levels of carbon monoxide (CO) and sulfur dioxide (SO_2) did not exceed Hawaii standards. The table below gives 1-h average levels of CO for Fort Street Mall south [the state CO standard is 10 mg/m^3 (8.7 ppm)] (1 mg/m^3 = 0.87 ppm):

Time Period	CO (mg/m³)	Time Period	CO (mg/m³)
9:30-10:00 a.m.	5.75	11:00-11:30 a.m.	5.75
10:00-10:30 a.m.	5.2	11:30 a.m.-12:00 n.	4.0
10:30-11:00 a.m.	6.3	12:00 n.-12:30 p.m.	4.6

The table below gives the 3-h average levels of SO_2 observed (the state SO_2 standard is $400 \mu g/m^3$):

Time Period	SO_2 ($\mu g/m^3$) Fort Street Mall	Bishop Street
10:00-11:00 a.m.	2.3	3.3
11:00 a.m.-12:00 n.	2.3	11.4
12:00 n.-12:40 p.m.	3.4	12.2

CONCLUSIONS

A brief discussion of the conclusions of the study is presented here. A more detailed discussion is available elsewhere (4).

Bus Movements

The Hotel Street bus demonstration indicated a bus capacity of 95-100 buses/h. This falls within the highest observed volume range (90-120 buses/h) on single-lane, downtown streets with on-line bus stops (1, 3). However, average bus speeds through Hotel Street were 3-5 km/h (2-3 mph) rather than the 8-16 km/h (5-10 mph) associated with the highest observed volume in other areas.

In the eastbound direction, the limiting bus volume passed through Hotel Street at Richards. Data at this intersection indicated that bus capacity in the eastbound direction was about 100 buses/h. A major bottleneck was located on the Nuuanu-Bethel link. The average link speed was about 2.4 km/h (1.5 mph) during the heavier flow rates, the lowest through the system in the eastbound direction. The Smith-Nuuanu link, the immediate upstream link, also recorded below-average system speeds during the 24- and 26-s-headway test periods.

In the westbound direction, minimum bus volumes passed Hotel Street at Fort Street Mall. Data at this intersection indicated that westbound bus capacity on Hotel Street is about 95 buses/h. The first major bottleneck identified was located on the Richards-Alakea link. Travel speeds on this link averaged 1.8 km/h (1.1 mph) during the heavier flow rates, the lowest through the system. Average link speeds were also below the average system speed on the Alakea-Bishop link during the attempted 26- and 24-s-headway test periods.

During the demonstration, it was observed that bus stops were a major bottleneck. Average speeds on links with nearside bus stops had the lowest link speeds compared with links with midblock or farside bus stops.

In 1967, the Institute of Traffic Engineers recommended the placement of nearside bus stops at signalized intersections where transit movement (assuming low bus volumes) is critical and parking and traffic are not (6). However, from the limited observations made in this study, it appears that nearside bus stops at signalized intersections are not superior to midblock or farside bus stops with respect to speed or travel time for heavy rates of bus flow. However, further analysis must be done to verify this conclusion.

Other Vehicle Movements

Twenty-four-hour traffic counts at selected sites along Hotel Street indicated no significant differences in traffic volume during the 24-h period and the 2.5-h test period for the test day and other previous days. Travel time studies showed that, although overall automobile speeds were higher than bus speeds—usually by almost 100 percent—automobile speeds were adversely affected by high bus volumes. Checks of queue length on side streets during the experiments showed no problem.

Pedestrian Movements

The intersection at Hotel Street and Fort Street Mall served the largest pedestrian demand: 6394 pedestrians between 10:00 a.m. and 12:30 p.m. A signalized crosswalk is located at this intersection to satisfy this large pedestrian demand. This additional pedestrian signal adversely affected bus movements on Hotel Street. Since at other locations along Hotel Street pedestrians crossed Hotel Street with cross vehicle traffic and no significant number of jaywalkers were recorded, pedestrian movements were not a problem at other intersections.

Environmental Impacts

No air quality problems were recorded by the Hawaii Department of Health. Wind speed and direction were 33 km/h (20 mph) east-northeast with gusts up to 46 km/h (29 mph) during the day.

Four occurrences of noise levels exceeding the state standard of 92 dB(A) were recorded along Hotel Street at Bishop. This probably resulted from the sound-reflecting background at that location since the same buses did not exceed the state standard at other locations.

It should be noted that current state noise standards for vehicles are defined for distances between 6 and 15 m (20 and 50 ft) from the source. However, bus noise on Hotel Street will have its greatest impact on pedestrians located on the adjacent sidewalk. Since sidewalks are located at the edge of the roadway and are approximately 2.4 m (8 ft) wide, noise levels experienced by pedestrians could be higher than 92 dB(A). This is an important factor in considering high bus volumes on Hotel Street and the application of existing state noise standards to CBD areas.

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K. Hayashida was with the Honolulu Department of Transportation Services when this study was performed.

Discussion

Herbert S. Levinson, Wilbur Smith and Associates

The paper by Hayashida, Fujita, Hamayasu, and Lum provides a much needed addition to the state of the art on bus capacity. It is indeed gratifying to find research based on actual field tests. The findings are generally consistent with the range of values reported for other downtown areas. They show what bus capacities can be realized without the "leapfrogging" of buses.

The authors found that bus speeds declined as flow rates increased. Westbound, speeds dropped from about 8.5 km/h for a flow of 60 buses/h to about 4.0 km/h for a flow of 100-120 buses/h; eastbound, speeds declined from about 9.3 to 4.0 km/h for the same increases in bus flow rates. More detailed analysis of these relations would be desirable to allow a level-of-service concept to be introduced into the analysis.

The paper implies, but does not clearly state, that passengers boarding and alighting from regularly scheduled buses at major load points limit the capacity of the system (as at Bethel and Alakea eastbound and Fort Street Mall westbound). More analysis and interpretation of the interrelationship between regularly scheduled and test buses are desirable.

Important information is lacking in several areas:

1. It is not clear how many automobiles traveled in the bus lane during each test period. These automobiles occupy a portion of the green time that would otherwise be available for buses.
2. The effects of multiple use of bus stops and use of multiple berths are not clearly specified. Data on the amount of bus queuing at bus stops along Hotel Street seem to be lacking (the authors indicate that two buses are allowed to load and unload simultaneously at each stop).
3. The effects of varying the dwell times of test buses are not indicated.

The analysis would be strengthened by a fuller discussion of certain operational recommendations that emerged from the research. Can capacity be increased by providing only farside stops? by dispersing loading points? by lengthening bus stops? Perhaps answers to questions such as these can form a logical extension to this important and timely research.

Ann Muzyka, Transportation Systems Center, U.S. Department of Transportation

The Honolulu Department of Transportation Services is to be commended for undertaking the experiment described by the authors. Data collected in the field under operating conditions are extremely valuable; they are needed to keep analysis in touch with reality. The amount and variety of data collected are impressive. The negligible influence of increased bus volumes on pollution and noise levels is significant. This study will be valuable for other researchers in planning similar experiments as well as in developing theories and procedures for estimating capacity. Such analytical techniques must account for the facts developed in this study.

It is clearly stated that the objective of this experiment was to determine bus capacity under existing conditions. Therefore, the traffic signal timings, traffic volumes, and bus stop locations remained constant. The parameters of traffic signal timings, especially the offset pattern, are very important in filtering the movement of vehicles (7). A useful future study would be an analysis and field experiment to determine the influence of traffic signal timings on street capacity for buses. An appropriate performance measure would be person throughput rather than vehicle throughput.

I understand the increase in bus volumes is contemplated to improve the level of service for current demand and not to accommodate projected increases in demand. Additional no-passenger buses used in the experiment were given 15-s dwell times at each bus stop to simulate passenger loading, and these data were not separated from the dwell times of buses that carried passengers. It would have been useful to separate service times for the two types of buses. In addition, an explanation of why the 15-s dwell time was chosen for all no-passenger buses would be interesting.

In summary, the paper is well written and extremely interesting. This study is significant for its direct approach of metering bus-flow rates until saturation is reached, a common practice in simulation studies. It is a valuable source of field data, which provide the acid test for relevant theories and models. The demonstration procedures and results will be useful to all planners of similar experiments.

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