EXPERIENCE AND EVALUATION OF A TESTING PROGRAM IN AN UNDERDEVELOPED AREA AS A MEANS OF DEVELOPING A ROAD CAPACITY ESTIMATING METHOD

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In another paper I mentioned the importance of speed and lead as determinants of road capacity. When I first began to look at the problem, in May 1962, I could find no evidence of field tests to gather this kind of data, especially on the types of roads found in Southeast Asia. Previous RAND work had encountered the influence of road capacity estimates on threat estimates, therefore it was timely to seek support for some field work. Fortunately, with the support of ARPA** through its field unit at the Combat Development and Test Center in Bangkok, we were able to arrange and conduct a series of tests on roads in Thailand. The Royal Thai Army offered invaluable cooperation and furnished equipment and personnel for the tests, which took place in October-November 1962 and in October 1963. In both cases this was right at the end of the monsoon season. We had hoped to operate during the rains in the 1963 test, but missed them; however, it gave us an opportunity to observe a year of change on some of the test routes.

THE FIELD TEST (1962)

In the course of making off-road mobility tests and environmental studies, ARPA/Bangkok had already accumulated some knowledge about roads in Thailand. On their recommendation, and after five days of reconnaissance in a Land Rover, we adopted the five adjoining test

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**Advance Research Projects Agency, Department of Defense.

routes shown in Chart 1. Note that we were frustrated in making longer loops by the two washouts shown. I will show you the characteristics of these routes later.

Data accumulated during the reconnaissance included road descriptions, photographs, the locations of transition points and bridges, bridge descriptions (we were also concerned about safety), and altitude readings on the mountainous portion of the course. We requested a truck company from the Royal Thai Army but were only given four trucks because of other commitments. We made our plans to obtain as much information as possible with this small number of trucks. We furnished our observers with detailed descriptions of each route, including the distance to each bridge and other landmark. We also used AMS Map Series L509 (1:250,000).

Chart 2 shows the equipment and personnel we used. The 55-gallon drums were used as cargo . . . filled with water for the "loaded" runs and emptied for the "empty" runs. This saved a lot of hard labor in loading and unloading trucks. Allowing for some spillage, the payload on each truck was about three tons and on each trailer about 3/4 ton. The gross weight of a loaded truck-trailer combination was approximately 10 tons. (These Toyota trucks are somewhat lighter than a U.S. 2½-ton truck.)

A Tachograph mounted on each truck kept a continuous record of speeds achieved and distances covered as a function of time; also, of times when the engines were running. Chart 3 is one of the actual Tachograph charts from the test runs. The observers were Thai engineering students who spoke reasonably good English. Mr. Morrison and I also served as observers. The tape recorders were essential because road roughness made it impossible to take written notes. Observers were asked to record the following, usually on an assignment basis:

Noting of checkpoints and landmarks along with odometer and clock readings.

Observation of road characteristics, construction, and maintenance.

Spot recordings of speedometer, odometer, and clock readings at frequent intervals, especially at low speeds, to augment Tachograph data.

Measuring roadway width by means of a calibrated scale on the windshield.*

Maintaining, in 5-minute blocks, a "basketball score" of all opposing traffic by type of vehicle (this was marked on a form).

Noting of reasons for speed limitations, stops, etc. Observing of vehicle spacings, dust conditions, and the effect of traffic (spacings were estimated by eye).

All observations were transcribed onto a standard written format during the off-days between runs, while the data were still fresh in our memories. Our trucks made short rest stops almost every hour and we scheduled off-days quite frequently to avoid overfatigue. Some of those roads were very rough on humans, but the Thai drivers performed beautifully and seldom complained.

Our experience in Thailand was quite satisfactory. One reason why we couldn't get more trucks and drivers was that the Thais were limited in what they could spend for troop per diem in the field; another reason was that they couldn't spare us very many trucks. Logistic support was good, including truck maintenance and messing and billeting for the Army personnel; this could have been a problem had we operated at a greater distance from Bangkok. The trucks held up well, with occasional flat tires on the rougher cobblestone roads. The trailers, however, were flimsy and began to fall apart. Having a mechanic with us helped. The Thai engineering students were conscientious and capable.

DATA REDUCTION

The Tachograph charts provided the best source of data on truck speeds once we had divided the test courses into fairly homogeneous segments using observer notes. We enlarged the Tachograph charts photographically and made a vernier to fit the enlargements so that we could read the clock time at each kilometer mark to the nearest half-minute. These readings were fed into our computer to obtain average segment speeds. Chart 4 summarizes average speeds for all trucks and all runs.

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*Some more accurate measurements had also been made during the reconnaissance.

A study of Chart 4 reveals some interesting facts. Night runs, for example, were faster than day runs on 21 out of 34 segments of 4 km or longer. Also, empty runs were faster than loaded runs in 12 out of 19 segments of 4 km or longer. The one mountainous segment (Course Three, Segment 19, 16 km long) was the descent from Korat plateau to the neighboring lowlands. One might not expect that the average downgrade speed on this segment was 33.1 kph while that of the upgrade was 31.5 despite the fact that grades up to 10 percent were encountered. The apparent reasons for this are that the average grade was only about two percent and that the average speed on a similar surface on flat terrain was 36 kph. The type of surface therefore probably had as much effect as the gradient upon speed.

Chart 4 also illustrates the difficulties inherent in classifying any road by condition and terrain. Here are some examples of variations in average speeds for several categories of daytime runs with cargo:

Bituminous/fair/flat	29.0; 36.3
Bituminous/good/flat	59.3; 65.3; 74.3
Cobblestone/fair/flat	33.8; 34.7; 35.6; 42.1; 44.5
Cobblestone/good/hilly	42.6; 48.1

It is often difficult to decide whether to define a road as being in "fair" or "poor" condition, since such definition is a subjective matter. If, for instance, an observer has just been over a very rough stretch of road, a paved section may look and feel "good" to him. A paved section in the same condition may seem "fair" or even "poor" to an observer who has just come from a first-class highway. The same problem of defining or categorizing terrain accounts for the considerable variation of speed which occurs within the same general category. Segment 19 of Course 3 would be termed "mountainous" because of the grades and curves it has, but since there were only a few really sharp curves or steep grades on this segment, the average speed during the test runs was more than 30 kph.

Allowances having been made for the variations of speed within the same category, the test speeds shown in Chart 4 were averaged and consolidated by road type to form the basis for the operational speeds developed for our method.

Driver motivation is another factor which is not shown in these charts of average speeds. Often the return run on the same course would be much faster due to what we called the "home-to-the-stable" factor. The drivers' eagerness to get back overcame their fatigue. This was true even on Course 3, which took the most time (about 12 hours, including stops). In one extreme case a truck fell behind 20 minutes because of battery trouble. Driving at breakneck speeds over Course 3, Segments 2-10, this truck managed to catch up with the rest of the convoy in less than 40 minutes.

Chart 5 shows some spot speed observations as a function of roadway width. There is considerable scatter although there does seem to be a trend, which we did not quantify, toward slower speeds on narrower roads. The narrowest roads occurred in the "mountainous" segment, making it difficult to separate the effect of terrain from the effect of width. The effect of width could not really be felt during the tests because opposing traffic was light; also, the narrower roads would not be used for actual two-way military traffic but they were being used as two-way roads during the test.

Gap and speed observations were made on a spot basis throughout the test. Some of these observations are plotted in Chart 6, including only those observations which mentioned both speed and gap.

Since there is considerable scatter in the data, the results do not show clear trends for the effect of condition and terrain on gap. It is interesting to compare the field data with the conventional definitions of close column and infiltration. The average values for all three surfaces are well into the open column category. The infiltration category (10 vehicles or less per mile) was usually reached only at the higher speeds.

Traffic was generally light during all of the test runs, as shown by the summary of traffic counts in Chart 7. The heaviest opposing traffic encountered was about 80 vehicles per hour on Courses 1 and 5.

On some courses truck traffic was heavier at night than during the day; on every course trucks predominated at all times over buses, cars, and other vehicles.

MULTIVARIATE ANALYSIS

Recently I used the data from Chart 4 in a multiple correlation routine to see what relationships could be detected between speed, width, terrain, condition, surface, day/night, and empty/loaded categories. The correlations were not impressive, but it was clear that condition and surface had the most effect on speed and that width and terrain had much less effect. The simple correlation coefficients are shown in Chart 8. Variables which are expressed as categories, such as terrain, were assigned dummy values ranging from 1 to 4 where 1 represented the worst condition and 4, the best condition.

Note the positive correlation of speed with condition* and surface, the negligible correlation with width, and the negative correlations with the day/night and empty/loaded categories. These last two relationships had already been noted: night speeds were better than day speeds, probably because the headlights gave advance warning of rough spots; loaded speeds were better than empty speeds, probably because of less jouncing. As expected, narrow widths corresponded to difficult terrain. One can also see that the unpaved roads tended to be wider than the paved roads and that the higher-grade surfaces tended to be in better condition.

Then I tried some other correlations, using observers' notes on spot speeds, gaps and dust conditions and the established descriptions of the test course segments in terms of surface, condition, and terrain. First I let speed be the dependent variable, with the results shown. Note that there is some correlation between gap and speed but that condition is still the dominant factor affecting speed, followed by surface type and amount of dust. Except for speed, nothing seemed to have any effect on gap.

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*To some undetermined extent this correlation was forced because we occasionally used test speeds to help decide on a condition category.

Finally, we let the ratio of speed to gap be the dependent variable. Here we see some correlation between speed/gap (which is directly proportional to road capacity) and condition, type of surface, and dust. It would take more test data and more precise measurements to verify these relationships, however this indicates two possibilities:

(1) road capacity does not vary as much with type of road as one might think because of the tendency of trucks to close up at lower speeds;

(2) condition may have more effect on capacity than the type of surface. Further, convoy doctrine probably has more effect on capacity than do road characteristics because doctrine would have a large effect on the ratio of speed to gap.

THE USE OF AERIAL PHOTOGRAPHY

We obtained complete aerial photographic coverage of the test courses. The photographs, made from planes flying at low altitude, resulted in 9" x 9" prints at a scale of 1:4000 to 1:6000. This particular set of photographs was of limited usefulness for the following reasons:

(1) The scale and exposure were such that considerable variations in road surface were not always detectable.

(2) Because the scale varied it was difficult to tell by measuring whether a road would be considered narrow or in some cases whether it would be suitable for two-way military traffic.

(3) The amount of observable detail varied markedly: in some pictures, even people and animals could be seen if they were casting shadows; in others, fairly large bridges were invisible because of overexposure.

With more careful exposure*, coverage at this scale would be useful for

*Ours were probably exposed for the darker vegetation, hence they overexposed the roads except in cloud shadow.

locating washouts, determining the number and type of bridges, noting gross changes in surface, and spotting sharp curves and areas with potential drainage problems.

To be more useful for estimating road capacity, photography would have to give us a closer look at the surface and a better measure of width. This might be effected by light aircraft flying at low altitudes and taking occasional detailed photographs at points were roads change significantly. Oblique photographs, in particular, might show surface detail better under the proper lighting conditions. There would also be a need for photo interpreter keys to aid in classifying a given road.

AVOIDING PREVIOUS LIMITATIONS

Our field tests had the following limitations which could be largely avoided in a more extensive test:

(1) Road categories. We were able to run tests on only about one-third of the possible combinations of surface, condition and terrain categories, not counting categories of width and dust. We had to extrapolate and interpolate, using physical relationships where possible, to obtain speeds and truck rates for use in our method. Also, multivariate analysis suffers when combinations are omitted.

(2) Convoy simulation and control. We had only four trucks and were not always able to keep the lead truck's speed down to what would be reasonable for a longer convoy, although we adjusted for this in estimating speeds for the method. Military control will be easier to maintain with U.S. personnel, jeeps, and radios. The main problem will be how to simulate an "endless" convoy. We might be able to do this with computer simulations techniques such as those developed by General Motors, trying increasingly long convoys until the behavior of trucks in the central part of the convoy remained the

same with further increases in convoy length. In the actual tests, then, we would gather data only from those trucks that were behaving as if they were in an endless convoy.

(3) Defining surface condition. This will continue to be a problem, important because condition has a substantial effect on speed and is hard to define, especially from intelligence data. We might try measuring various surface conditions with a profilometer, such as has been developed for the Land Locomotion Laboratory at Detroit Arsenal, then correlating these measurements with aerial photography to develop a standard set of photo interpreter keys. A surface might also be rated with an accelerometer mounted in a standard vehicle traveling at a standard speed, then correlated with photography. Surfaces that changed during the test would have to be rated at intervals.

(4) Measuring gap. In our test the gap between an observer's truck and the truck in front of him was simply estimated visually. Not only did this involve error, but we had no simultaneous readings of gaps between all trucks. This could be remedied in several ways: by providing observers with rangefinders and asking for gap readings at specified clock times; by aerial photography; by roadside observers using timing devices. The rangefinder method seems to be the easiest.

(5) Route reconnaissance. We reconnoitered our test routes in advance and recorded some characteristics data. We did not make any measurements of base thickness or any analysis of subsoil conditions. Our measurements of gradient were crude and the radii of curves in the mountainous area were estimated from aerial photography. Our width measurements were accurate but not frequent enough, so we augmented these with estimates made during

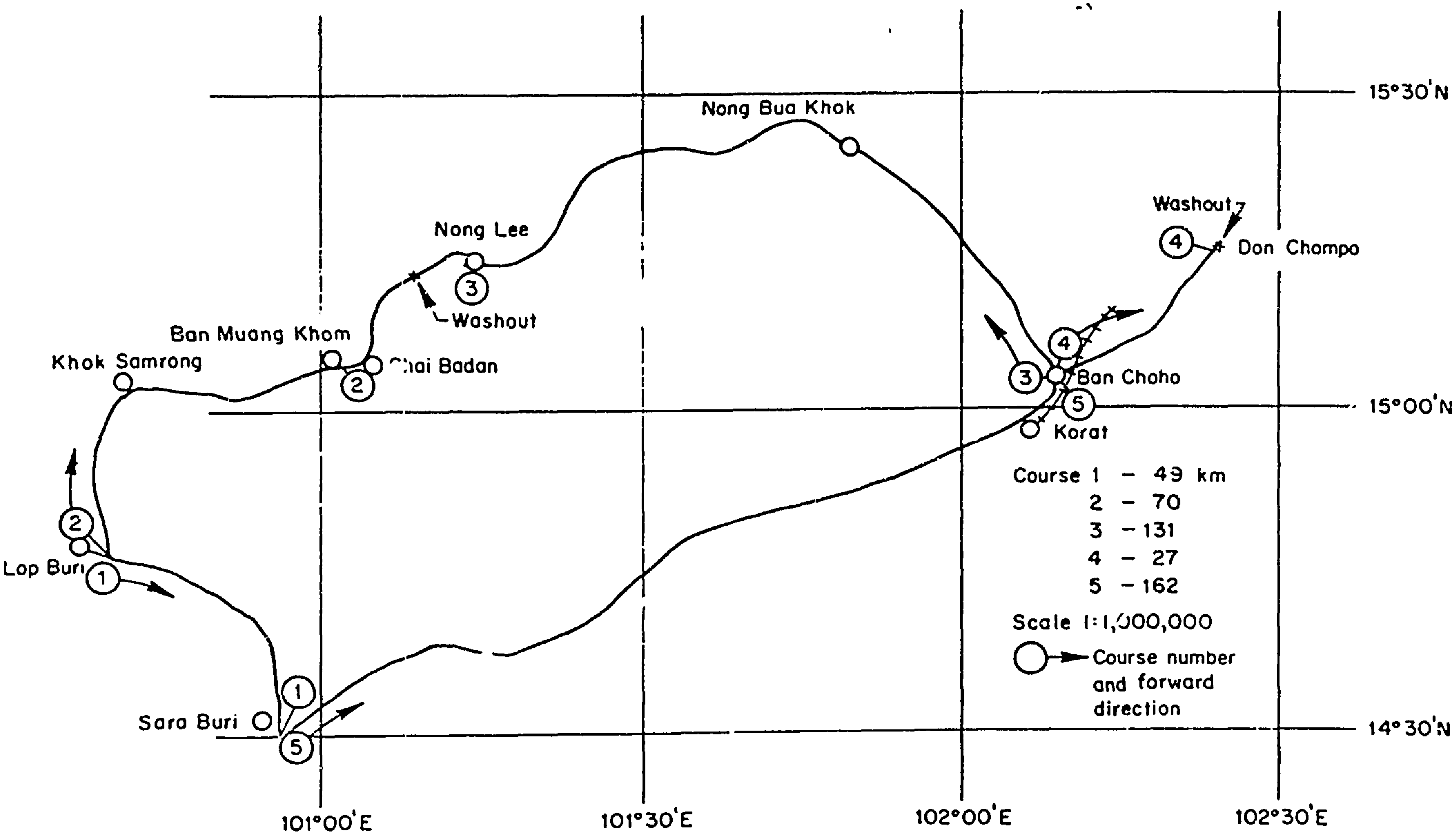
the test. Some combination of ground observations and aerial photography, backed up with photogrammetry, should yield a better route reconnaissance than we were able to accomplish.

(6) Counting other traffic. We had no control over other traffic and were able to count only vehicles that were moving in the opposite direction. Standard devices for counting traffic could be used and, particularly on one-way roads, non-test traffic should be controlled to simulate a wartime situation.

We recommend Tachographs as reliable instruments for making a permanent record of speed and elapsed distance vs. time. Tape recorders are essential for the observers because it is generally impossible to make written notes while moving. Cameras are useful for recording bottlenecks and other unusual conditions.

TEST LOCATION

Our reason for operating in Thailand was obvious: we wanted to be "on location" insofar as making capacity estimates for Southeast Asia was our main concern. For a larger test, however, it might be more feasible and less expensive to operate in the United States. Some of the larger military reservations have a variety of roads (e.g., Ft. Bragg, North Carolina). The driver training school near Monterey, California is another candidate location. Perhaps it would be necessary to test in several locations in order to cover a sufficient variety of roads. Matters of comparability with other countries could be discussed with environmental scientists at Waterways Experiment Station in Vicksburg, Mississippi.



General layout of test courses

Chart 1

EQUIPMENT AND PERSONNEL

EQUIPMENT

4 TOYOTA 21/2-TON DIESEL TRUCKS, ONE WITH WRECKING CRANE AND WINCH

2 ONE-TON TRAILERS

1 NISSAN JEEP

56 55-GALLON DRUMS

4 TACHOGRAPHS

4 PORTABLE TAPE RECORDERS

2 35-mm CAMERAS

PERSONNEL

2 AMERICANS (HOLLIDAY AND MORRISON)

2-3 RTA OFFICERS

3 THAI ENGINEERING STUDENTS (SEATO GRADUATE SCHOOL)

5 RTA TRUCK DRIVERS

1 RTA MECHANIC

1 JEEP DRIVER

Chart 2

TACHOGRAPH RECORD USED IN THAILAND FIELD TESTS

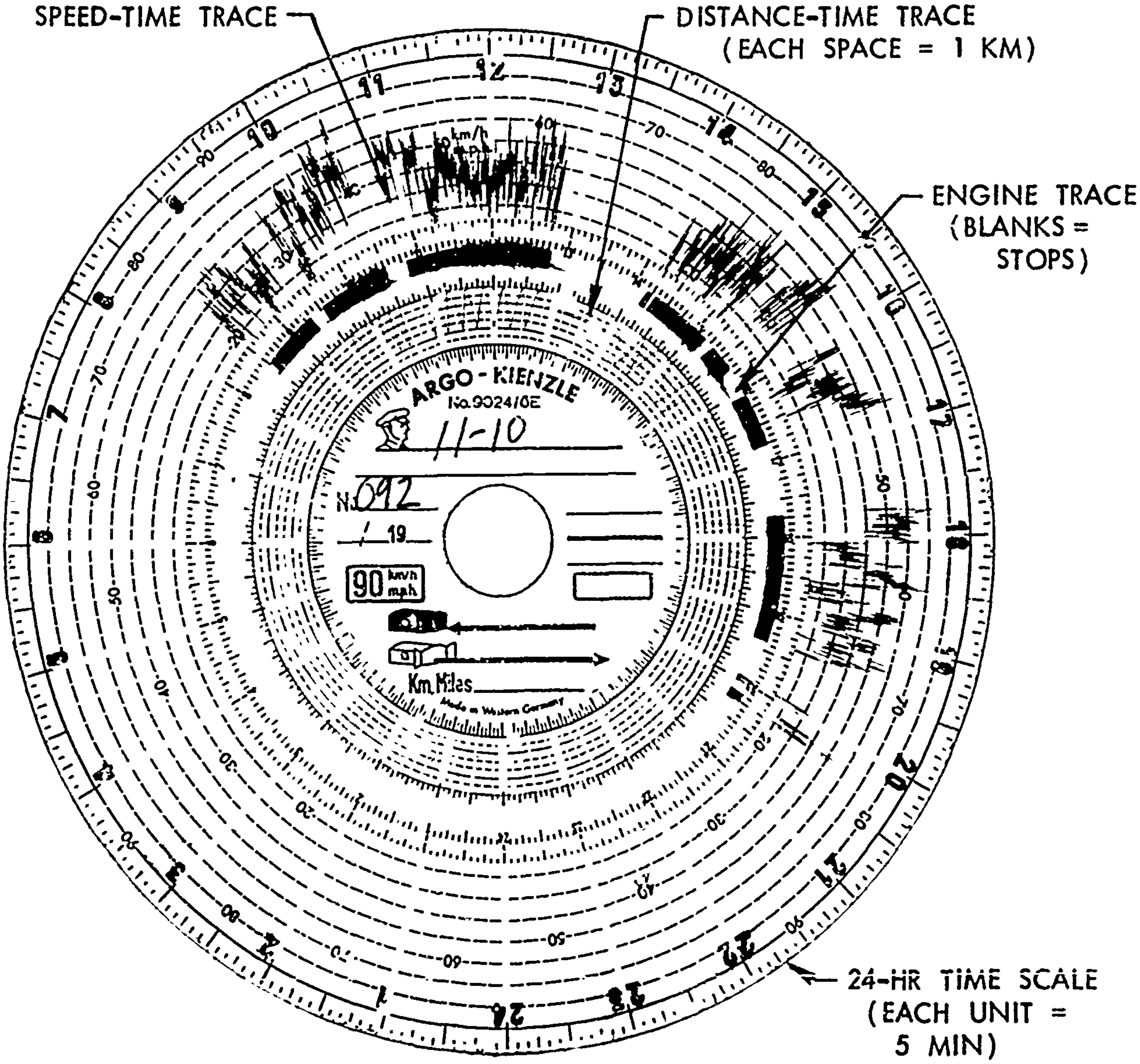


Chart 3

SUMMARY OF FIELD TEST SPEEDS BY COURSE AND SEGMENT

Test Course No.	Seg-ment No.	To km[a]	Length (km)	Surface	Condi-tion	Terrain	Road Width (m)[b]	Day Loaded	Night Loaded	Day Empty	Night Empty	Avg Speed
1	1	19	19	Bituminous	Fair	Undulating	5	51.4	56.9	--	51.2	53.2
	2	25	6	Bituminous	Fair	Undulating	5	44.8	57.5	--	48.8	50.4
	3	41	16	Bituminous	Good	Undulating	6	56.9	63.6	--	51.2	57.2
	4	48.8	7.8	Bituminous	Fair	Undulating	6	48.5	63.6	--	49.1	53.7
2	1	8.5	8.5	Bituminous	Good	Flat	6[c]	59.3	61.1	--	--	60.2
	2	20	11.5	Bituminous	Good	Flat	6	65.3	61.0	--	--	63.2
	3	33	13	Bituminous	Good	Flat	6	74.3	65.4	--	--	69.9
	4	39	6	Bituminous	Good	Undulating	4-5	49.8	56.5	--	--	53.2
	5	50	11	Cobblestone	Good	Hilly	5	48.1	45.7	--	--	46.9
	6	57	7	Cobblestone	Fair	Flat	5-6	44.5	42.1	--	--	43.3
	7	63	6	Cobblestone	Good	Hilly	3[d]	42.6	40.1	--	--	41.4
	8	70.2	7.2	Cobblestone	Fair	Flat	3	35.6	35.7	--	--	35.7
3	1	4	4	Bituminous	Fair	Flat	4-5	36.3	46.8	37.7	--	40.3
	2	7	3	Laterite	Good	Flat	6-8	45.4	37.8	35.1	--	39.4
	3	11	4	Laterite	Fair	Flat	6	33.6	37.4	33.5	--	34.8
	4	14	3	Bituminous	Poor	Flat	5-6	41.9	54.1	40.2	--	(e)
	5	18	4	Cobblestone	Good	Flat	6	42.5	40.5	32.2	--	38.4
	6	19	1	Laterite	Poor	Flat	6	29.7	29.1	42.0	--	(e)
	7	20	1	Bituminous	Fair	Flat	6	24.5	19.6	27.8	--	(e)
	8	22	2	Laterite	Poor	Flat	5-7	22.8	27.0	31.9	--	(e)
	9	30	8	Laterite	Fair	Flat	5-7	38.4	43.2	46.5	--	42.7
	10	41	11	Cobblestone	Fair	Flat	5-6	33.8	37.1	38.9	--	36.6
	11	44	3	Cobblestone	Poor	Flat	5-6	38.7	43.0	53.3	--	(e)
	12	48	4	Cobblestone	Good	Flat	5-6	43.2	50.2	38.7	--	44.0
	13	53	5	Cobblestone	Fair	Undulating	5-6	35.6	41.3	57.3	--	44.7
	14	57	4	Cobblestone	Good	Undulating	5-6	47.5	53.7	56.5	--	52.6
	15	79	22	Cobblestone	Fair	Undulating	6	41.9	45.5	40.5	--	42.6
	16	82	3	Cobblestone	Poor	Undulating	6	27.5	26.2	30.3	--	(e)
	17	86	4	Cobblestone	Good	Undulating	4	41.5	41.5	45.1	--	42.7
	18	109	23	Cobblestone	Fair	Hilly	3-6	35.4	36.4	38.9	--	36.9
	19	125	16	Cobblestone	Fair	Mountainous	3-5					
						(down)		33.0	31.8	36.4	--	33.7
						(up)		30.3	30.0	34.1	--	31.5
	20	130.8	5.8	Cobblestone	Fair	Flat	6	34.7	31.9	32.7	--	33.1
4	1	2	2	Laterite	Fair	Flat	12	35.4	57.6	41.6	--	(e)
	2	5	3	Laterite	Fair	Flat	10-12	35.0	48.6	49.4	--	(e)
	3	9	4	Laterite	Good	Flat	10-12	47.3	36.7	59.7	--	47.9
	4	13	4	Laterite	Fair	Flat	12	31.0	49.0	43.7	--	41.2
	5	15.5	2.5	Laterite	Fair	Flat	12	31.7	42.3	42.2	--	(e)
	6	20.5	5	Laterite	Poor	Flat	10	26.5	21.7	23.6	--	23.9
	7	24.5	4	Laterite	Poor	Flat	10	18.8	19.6	20.7	--	19.7
	8	26.5	2	Laterite	Fair	Flat	10	28.7	22.1	33.1	--	(e)
5	1	20	20	Bituminous	Exc.	Flat	10-12	67.8	75.0	--	--	71.4
	2	137	117	Bituminous	Exc.	Hilly	10-12	67.9	77.5	--	--	72.7
	3	153	16	Bituminous	Exc.	Flat	10-12	76.1	87.6	--	--	81.9
	4	156.9	3.9	Bituminous	Fair	Flat	10-12	29.0		--	--	29.0
	5	161.7	4.8	Laterite	Fair	Flat	6	34.7		--	--	34.7

[a] Forward boundary of segment (km from start of course).

[b] Not including shoulders.

[c] Each side of divided road.

[d] Usable width limited by piles of surface material.

[e] Segment length less than 4 km; not used in analysis.

Chart 4

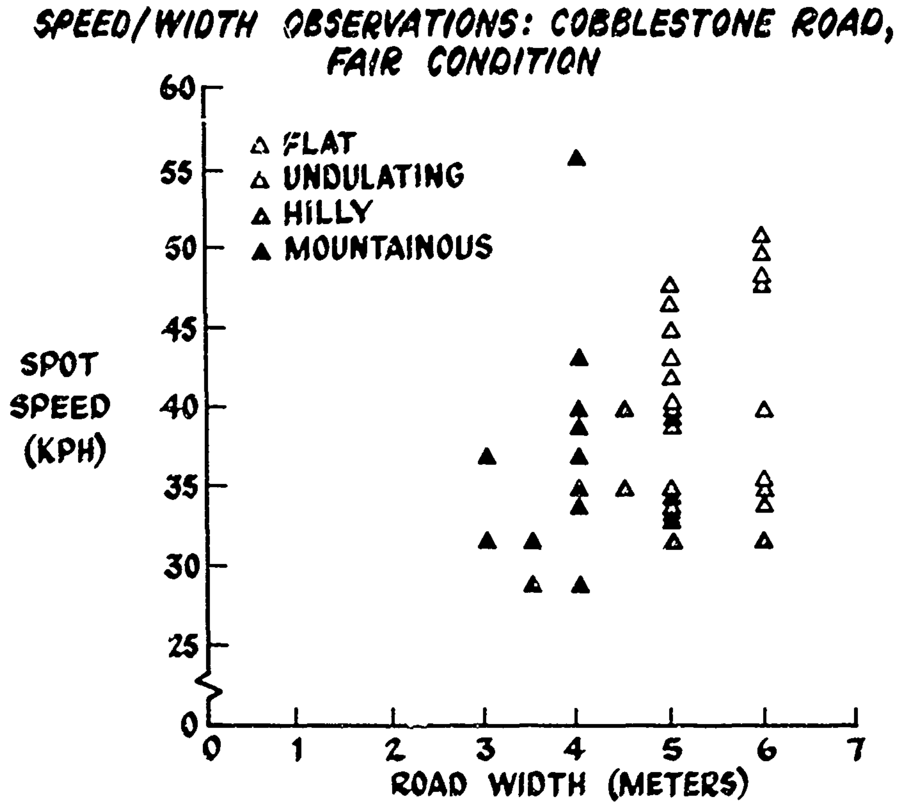

SPEED/WIDTH OBSERVATIONS: COBBLESTONE ROAD,
FAIR CONDITION
FLAT
UNDULATING
HILLY
MOUNTAINOUS
SPOT
SPEED
(KPH)
60
55
50
45
40
35
30
25
0
0
1
2
3
4
5
6
7
ROAD WIDTH (METERS)

Chart 5

FIELD TEST OBSERVATIONS OF GAP vs SPEED: LATERITE SURFACE

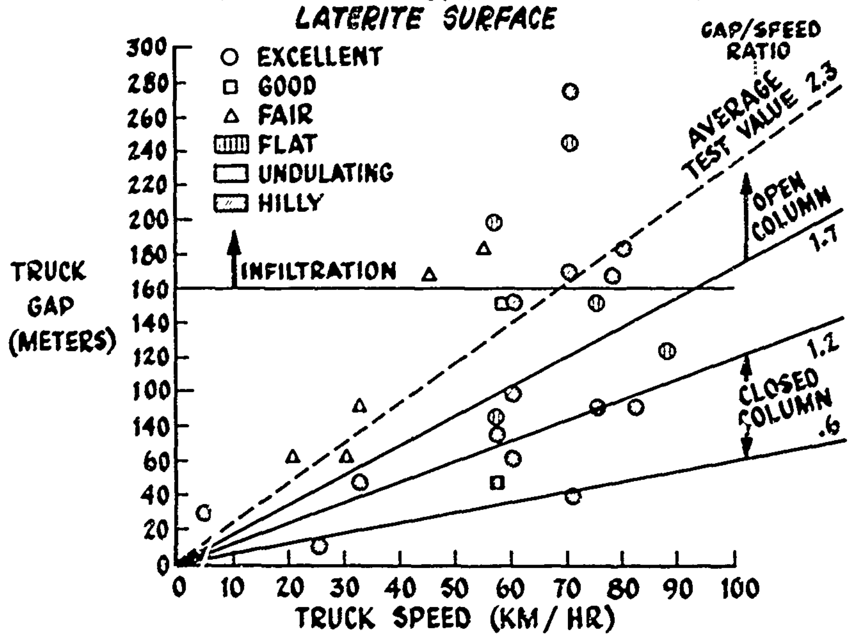


Chart 6

TRAFFIC DATA FROM FIELD TEST

Course No.	Date (Nov 1962)	Clock Time		Opposing Traffic Count				Day or Night
		Start	End	Truck	Bus	Car	Other	
1F	7	1003	1100	35	20	27	1 tractor, 3 oxcarts	D
4F	7	1459	1555	30	10	7	8 tractors	D
4R	7	1618	1712	17	4	2	5 tractors	D
5F	7	1153	1440	65	40	35	3 tractors	D
3F	8	0939	1519	15	22	4		D
3R	8	1549	2100	11	10	2		D, N
1R	11	1844	1938	16	8	16	1 tractor	N
4F	11	0929	1028	10	4	0		D
5R	11	1450	1737	80	42	42	1 tractor, 2 samlors	D
2F	14	0822	1042	25	15	14		D
2F	14	1915	2040	45	9	9		N
2R	14	1101	1240	36	14	9	1 tractor, 16 oxcarts	D
2R	14	2126	2249	31	1	6		N
1F	15	1915	2007	32	4	19	1 jeep	N
5F	15-16	2030	0053	85	3	8	1 jeep	N
3F	16	1856	2302	16	5	4	1 jeep	N
3R	16-17	2334	0359	2	0	1		N
4FR	16	0053	0223	9	0	1		N

Chart 7

SIMPLE CORRELATION COEFFICIENTS FROM FIELD TEST DATA

(1) USING AVERAGE SEGMENT SPEEDS

	WIDTH	TERRAIN	CONDITION	SURFACE	D/N	E/L
SPEED	.034	-.064	.651	.548	-.199	-.123
WIDTH		.420	.073	-.400	n.a.	n.a.
TERRAIN			-.144	-.251	n.a.	n.a.
CONDITION				.359	n.a.	n.a.

(2) USING SPOT OBSERVATIONS, INCLUDING DUST (EFFECT ON SPEED)

	GAP	SURFACE	CONDITION	TERRAIN	DUST
SPEED	.23	.32	.57	-.06	.33
GAP		-.05	-.06	-.004	-.04
SURFACE			.61	-.46	.90
CONDITION				-.24	.51
TERRAIN					-.50

(3) USING SPOT OBSERVATIONS (EFFECT ON SPEED/GAP RATIO)

	SURFACE	CONDITION	TERRAIN	DUST
SPEED/GAP	.14	.22	.02	.12
SURFACE		.61	-.46	.90
CONDITION			-.24	.51
TERRAIN				-.50

Chart 8