

Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington

Arthur N. Johnson (1870-1940)

Highway Research Board Proceedings, Vol 8, 1929, pp 106-115

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1

The historical context

The 60 first years of traffic measurement

Towards Johnson's aerial survey

1844: first French traffic census

STATE OF ILLINOIS HIGHWAY COMMISSION.
TRAFFIC RECORD.

Form No. 18

Object: _____ Date: _____ Road: _____
Condition of Road: _____ Loading Info: _____
Address: _____

HOURS AND WEATHER.	IN		OUT	
	LOADED	UNLOADED	LOADED	UNLOADED
6 A. M.				
7 A. M.				
11 A. M.				
12 M.				
1 P. M.				
2 P. M.				
5 P. M.				
6 P. M.				

REMARKS MAY BE MADE ON OPPOSITE SIDE OF THIS SHEET.

1926: Elements governing the growth of highway traffic

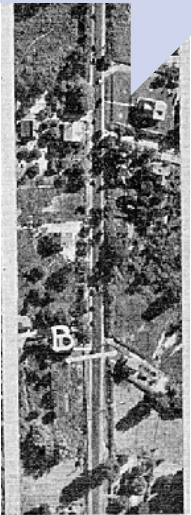
Johnson, 1929: Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington



1906: Johnson's traffic census on rural roads in Illinois

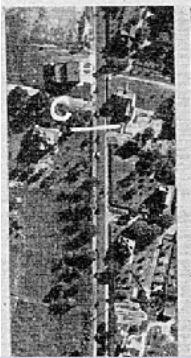
Counting vehicles to provide better road maintenance (higher traffic = increased pavement wear)

July 4th, 1927: aerial traffic survey of the Baltimore-Washington road for the State Roads Commission of Maryland



The 60 first years of traffic measurement

Aftermath of Johnson's aerial survey



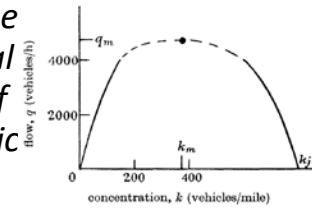
Johnson,
1933: *Notes
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Speed*



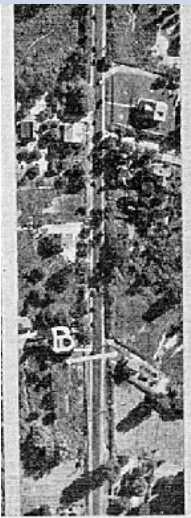
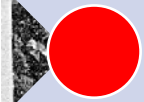
Normann,
1942:
*Results of
Highway-
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Studies*



Wardrop,
1952: *Some
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Aspects of
Road Traffic
Research*



Edie, 1963:
*Discussion
of traffic
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and
definitions*

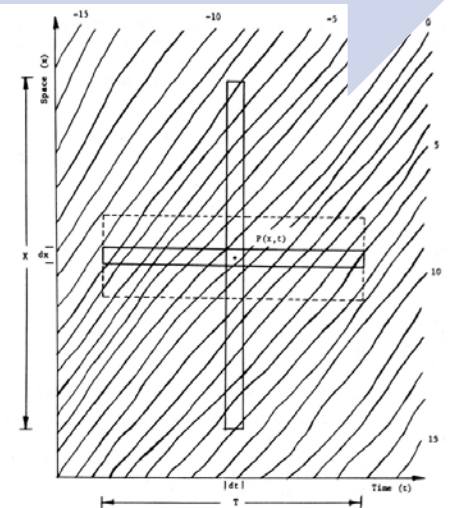


Johnson,
1931: *Traffic
Capacity*

Greenshields,
1934-1935: *The
Photographic
Method of
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Behavior*,
followed by *A
Study of Traffic
Capacity*

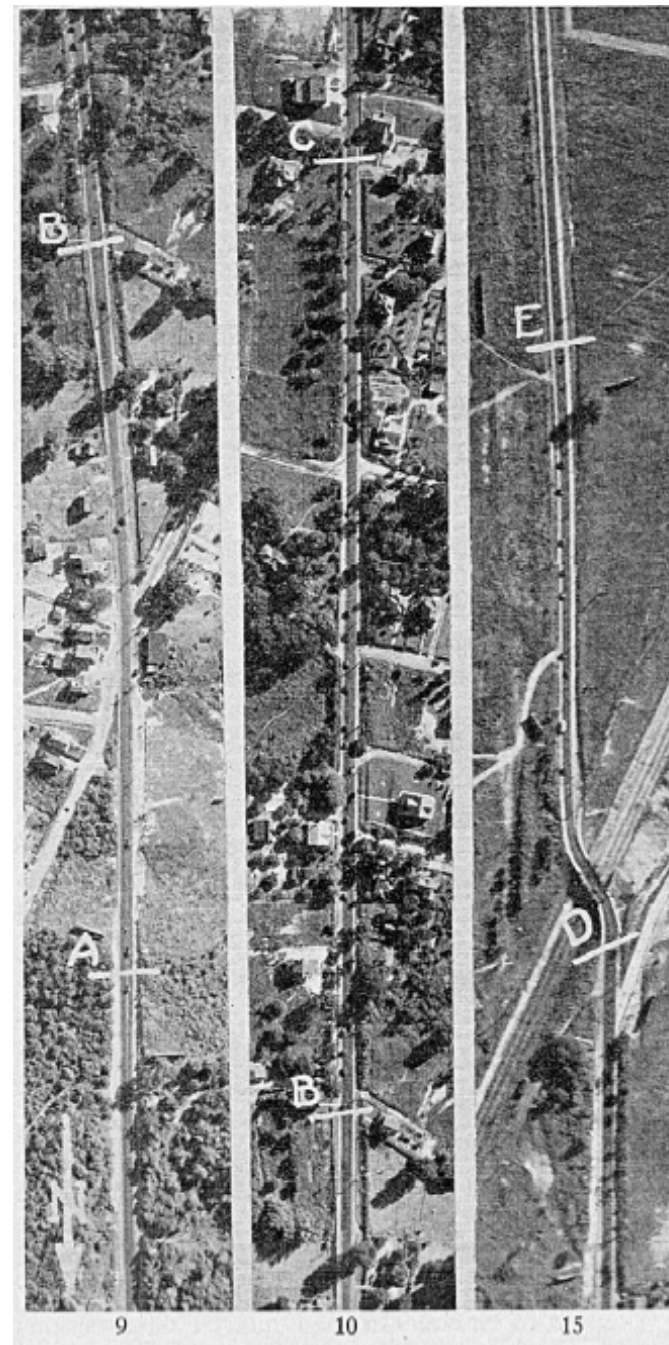
1950: first
edition of
the *Highway
Capacity
Manual
(HCM)*

Lighthill &
Whitham,
Richards,
1955-1956:
*On
Kinematic
Waves. A
Theory of
Traffic Flow
on Long
Crowded
Roads*

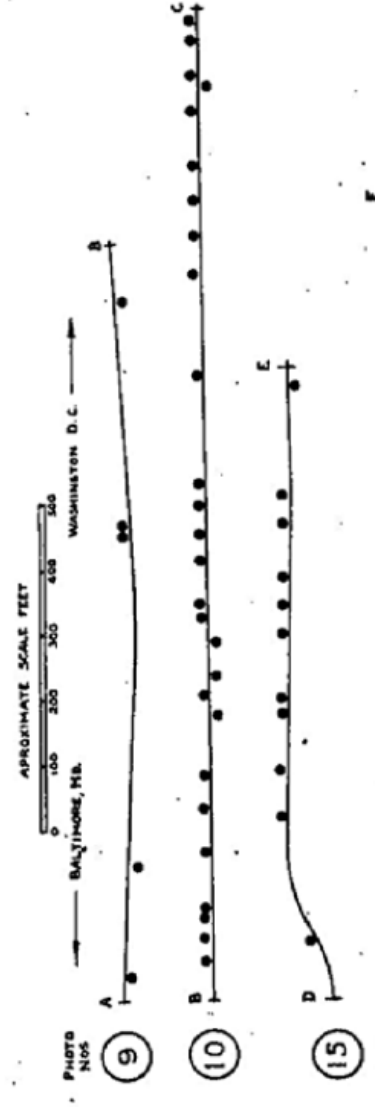
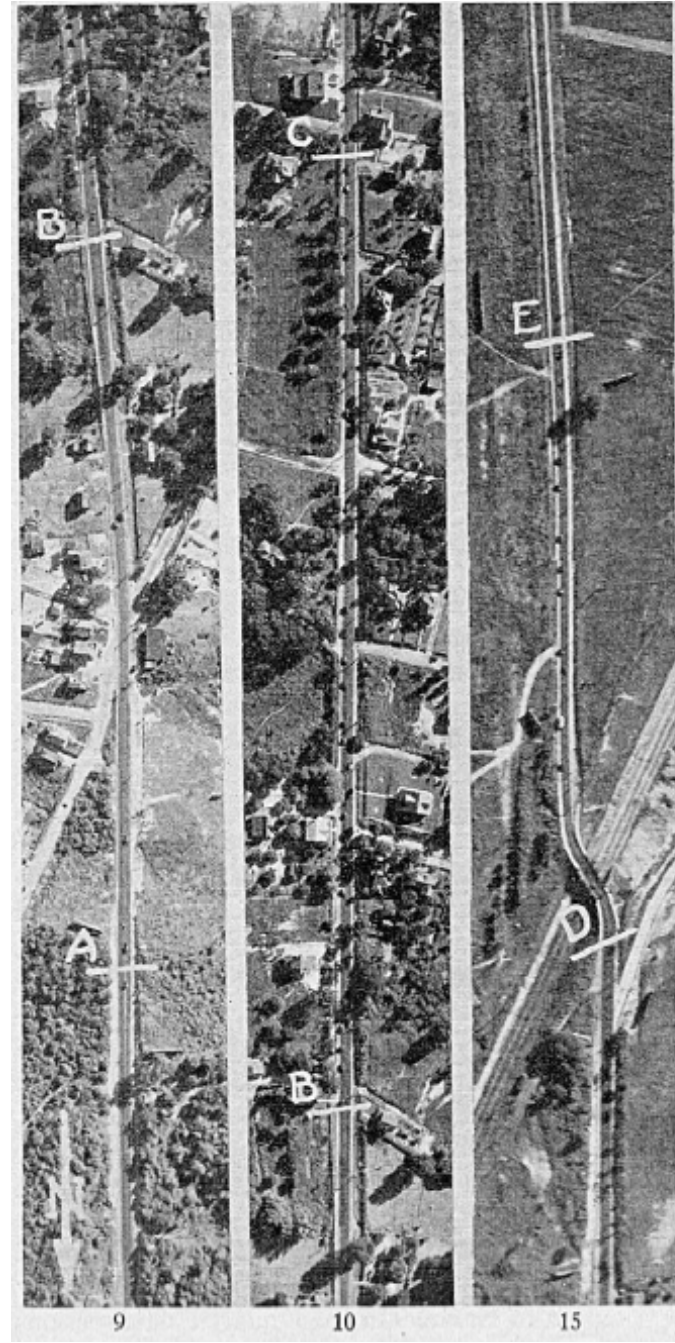


2

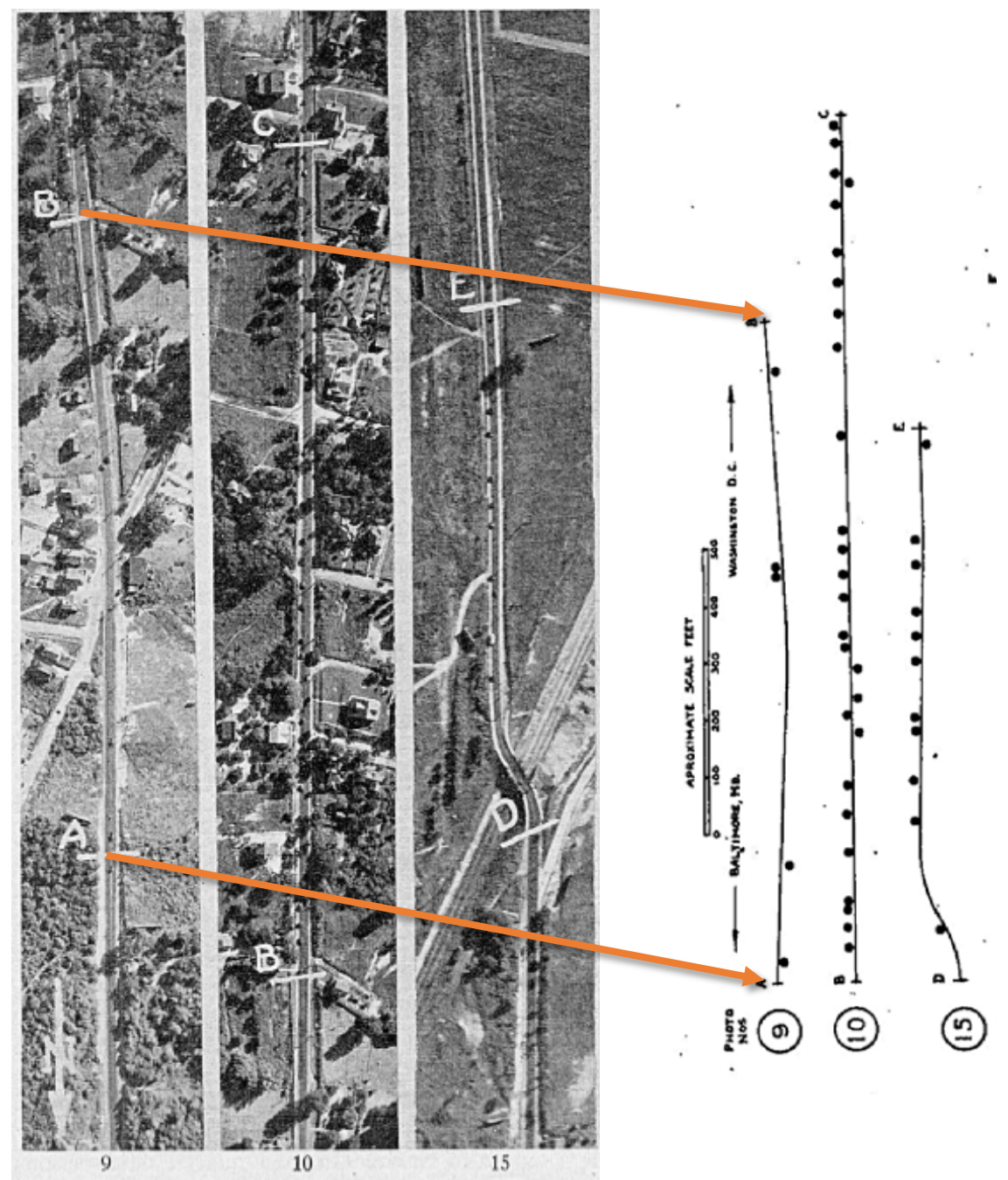
The content of Johnson's paper



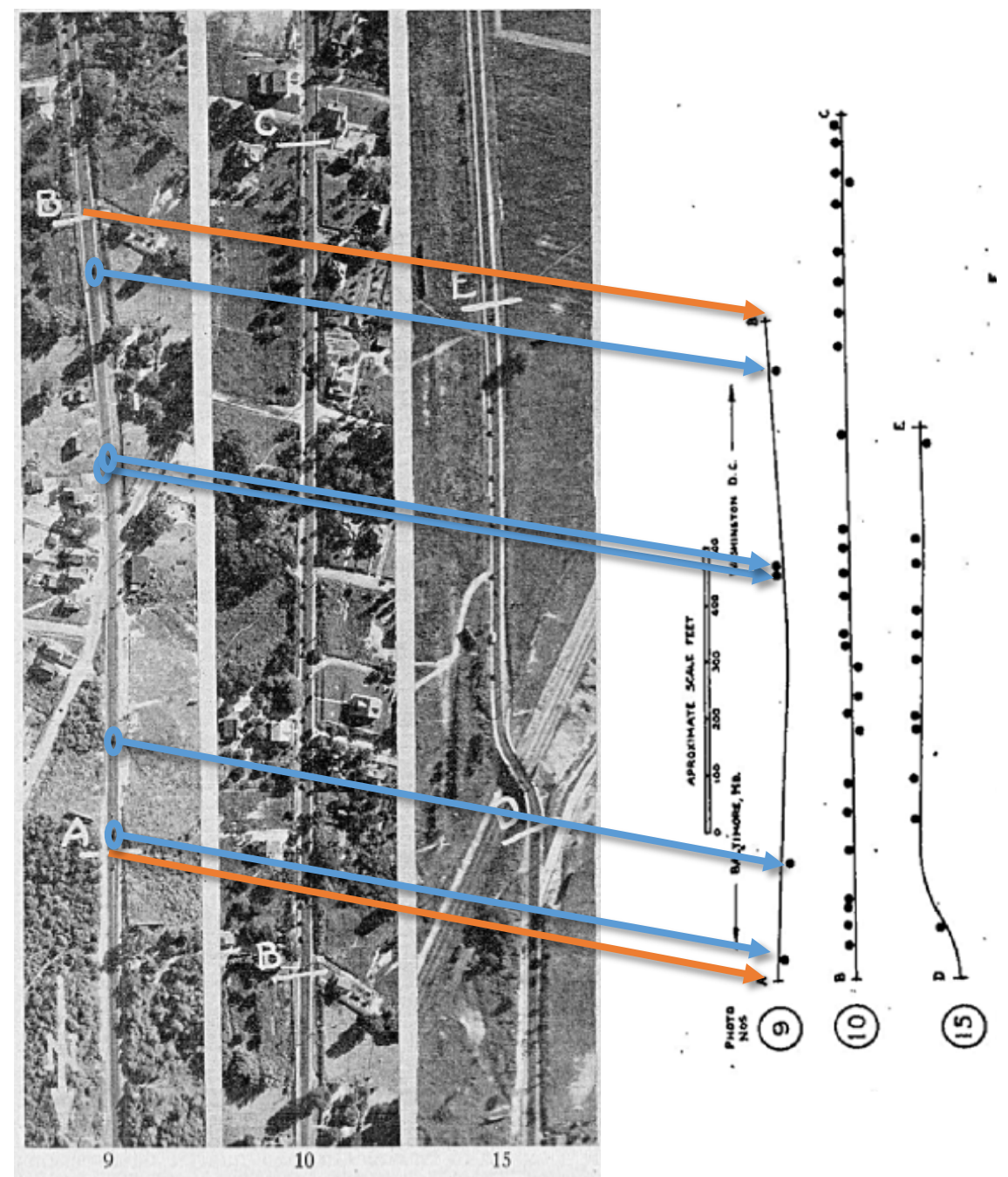
2 The content of Johnson's paper



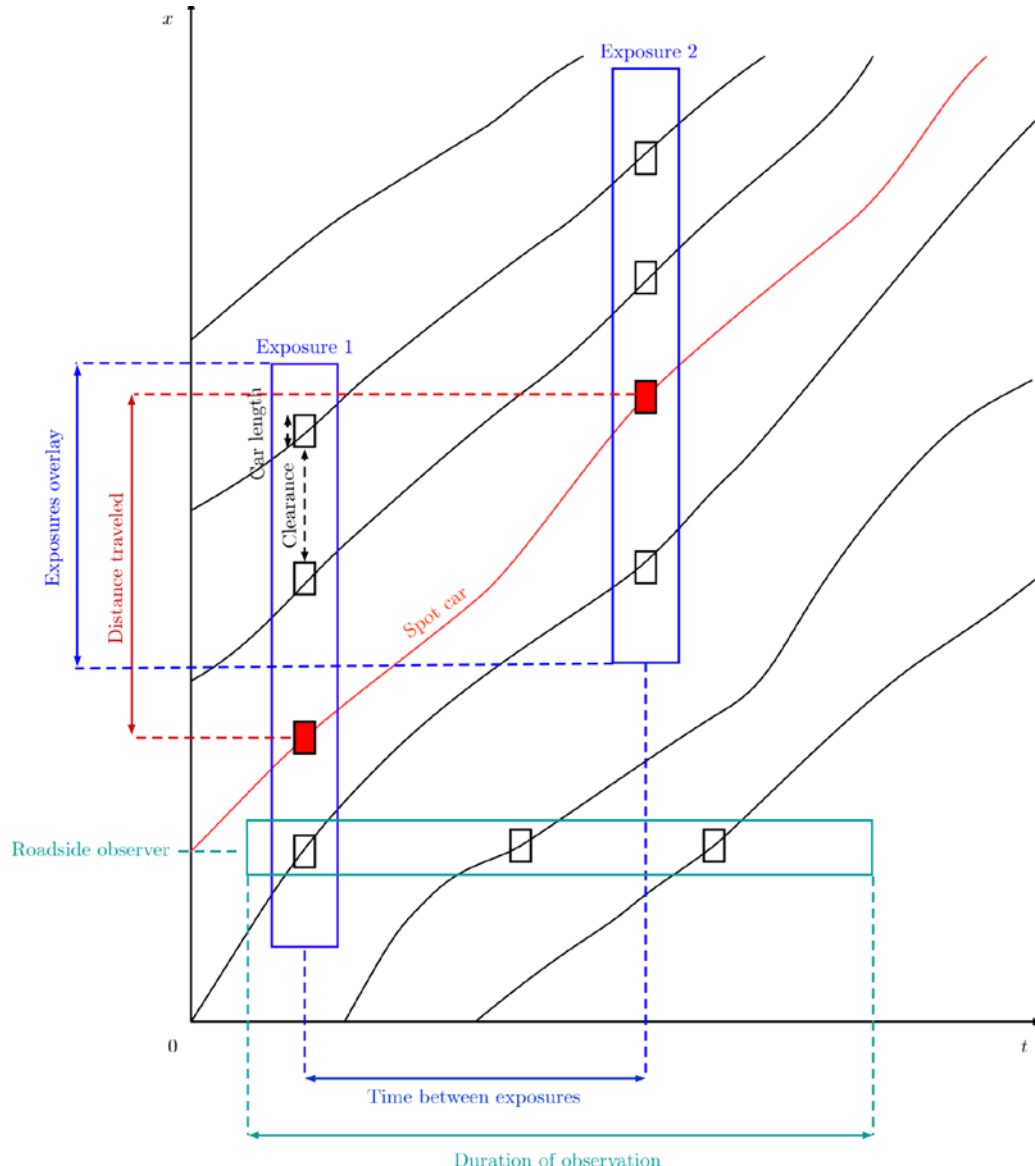
2 The content of Johnson's paper



2 The content of Johnson's paper



The experimental design



- **1 aircraft flying** over a 29-mile segment of the Baltimore-Washington road (27 minutes, 127 exposures, 50% overlap between two successive ones)
- **6 “spot cars”** fitted with a white sheet on their roof and a driver and an observer, “instructed to drive with the traffic”
- **4 road-side traffic count stations**, each fitted with 2 observers (one for each direction)

Results

The longitudinal density of traffic

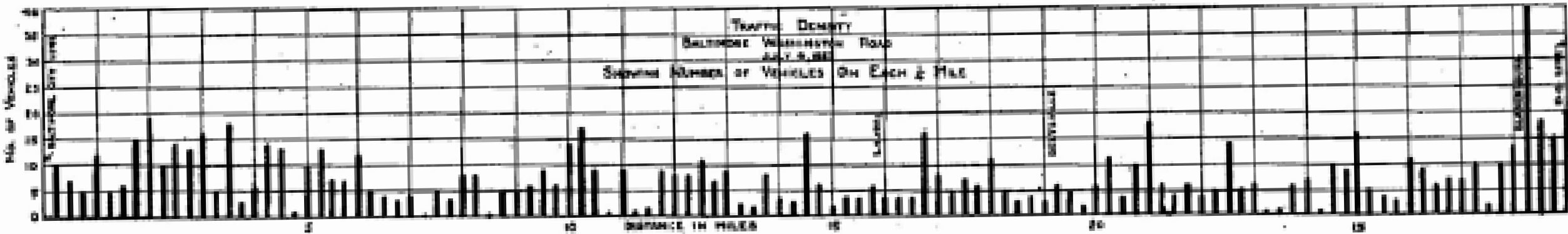


Figure 5

- “From Figure 5 may be seen that the average number of vehicles per quarter mile is about 7.”
- “At a speed of 25 to 30 miles per hours, 7 vehicles, per quarter mile would give an average flow of about 800 per hour, which was the number as shown by the actual traffic counts. “
- “From many observations of traffic on this particular road, it as been ascertained that a crowded condition occurs when the hourly rate over a 5-minute period lies between 800 and 1000 vehicles, that is it begins to be inconvenient for the faster moving vehicles to overtake a slower”.
- (Note: the hourly rate is meant in two directions)

Results

Johnson's fundamental diagram

- N : number of cars passing a given point at a given velocity V in miles/hour

$$N = \frac{5,280 \times V}{D}$$

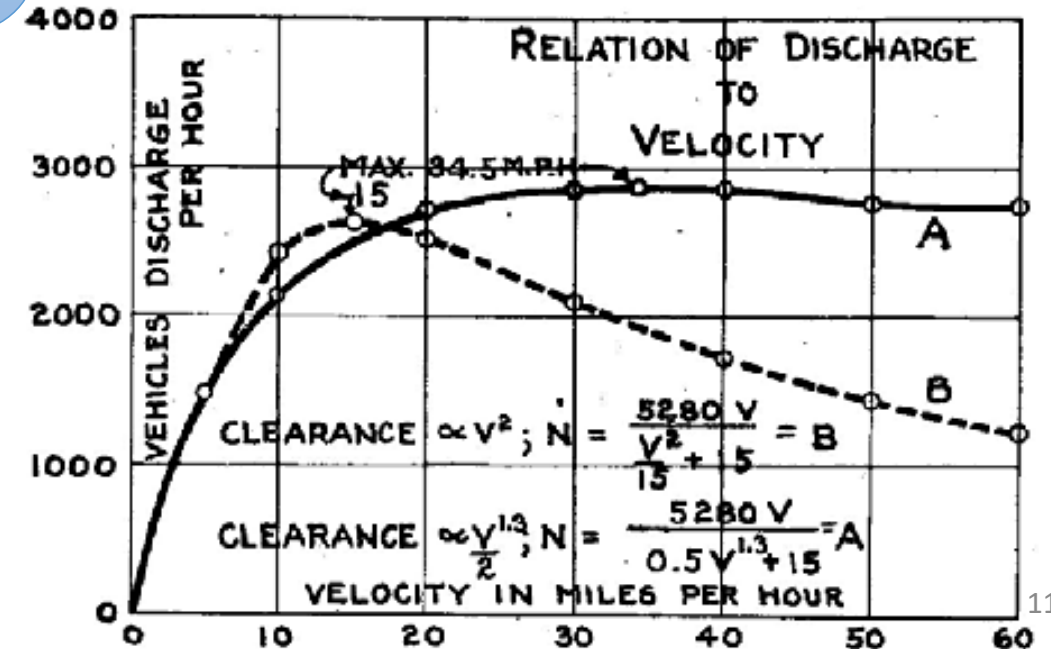
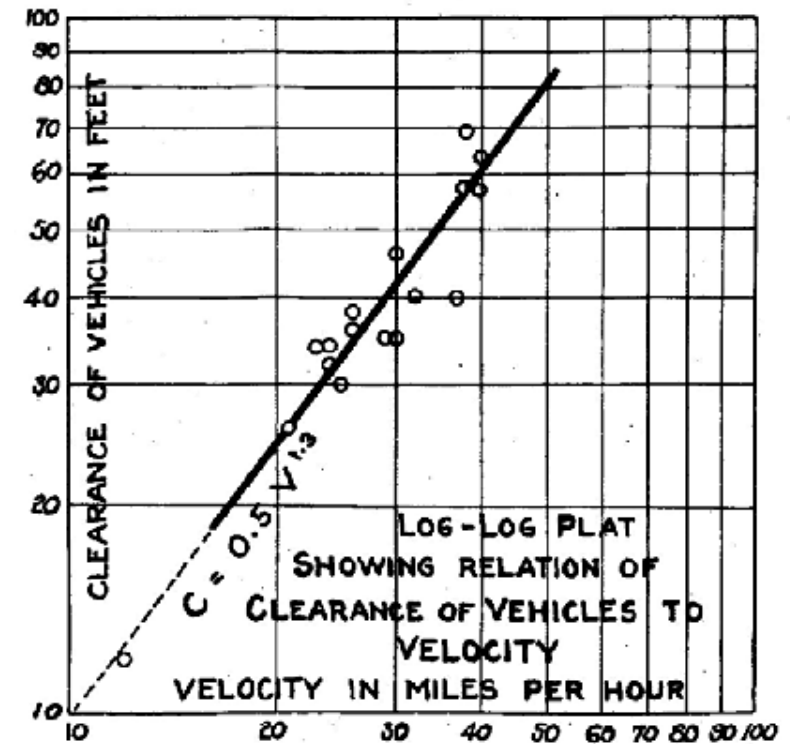
If you're not used to those (stupid) units, 5,280 simply is the miles/feet ratio

- D : distance between cars

$$D = C + \text{car length}$$

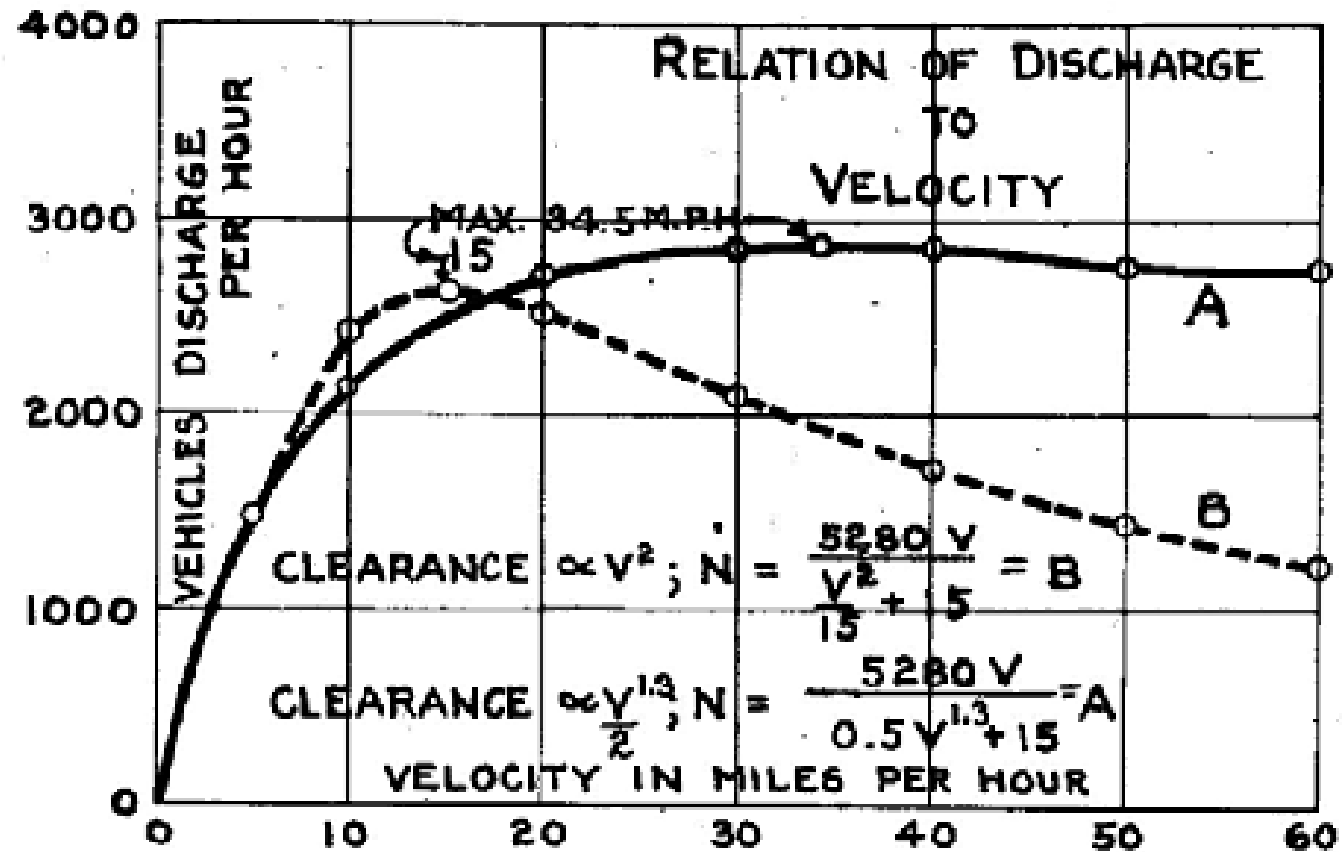
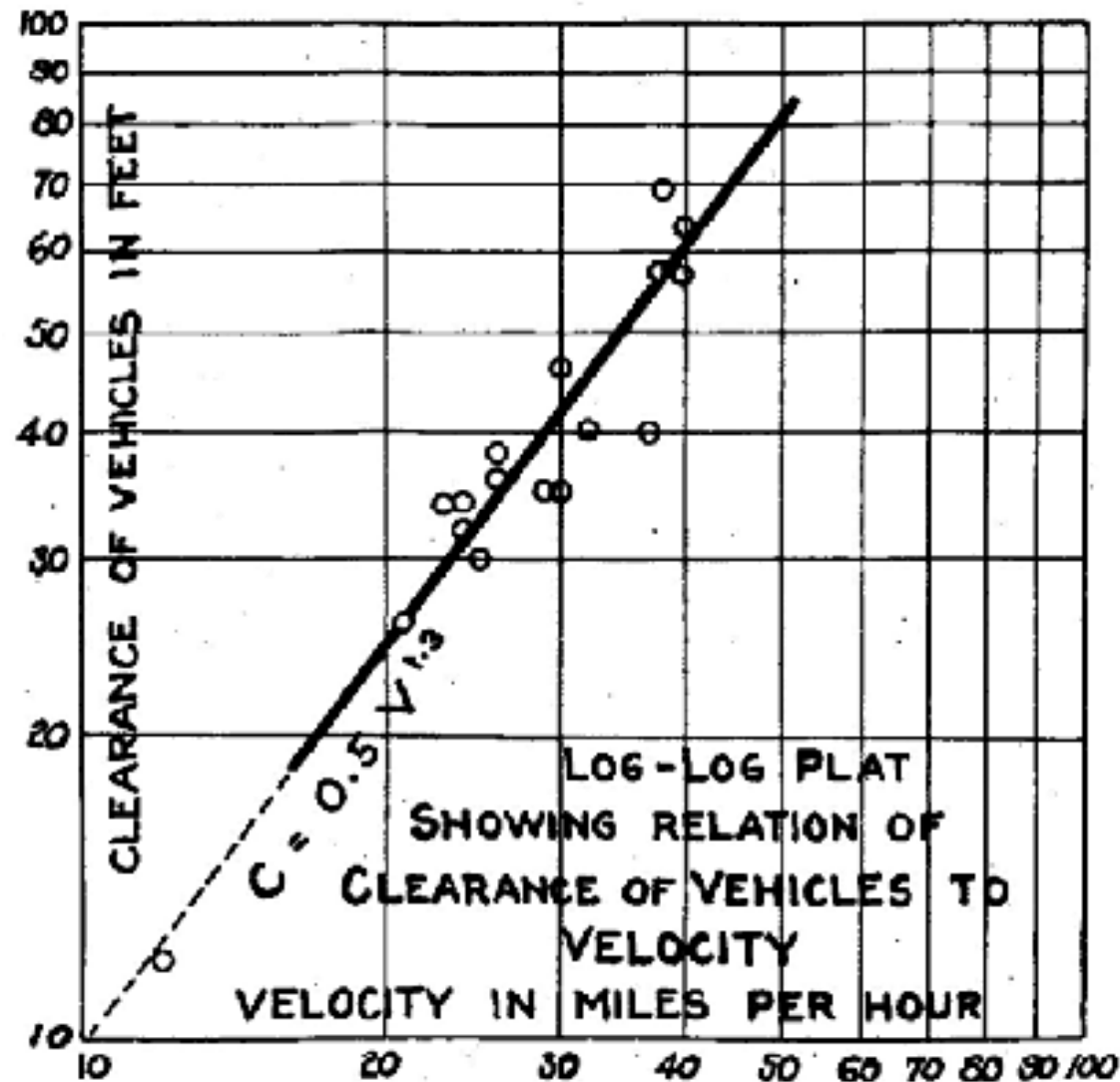
- C : clearance

$$C = 0.5 \times V^{1.3}$$



Results

Johnson's fundamental diagram



3

The limits of Johnson's work

The experimental issues

The unknown accuracy of the measurements

- “if the time between exposures was known accurately, as well as the scale of photographs...”
 - The photographs are not clearly timestamped
 - The photographs do not have a specific scale
 - The overlap between two successive shots is not constant

These limitations are mentioned by Johnson, but he nonetheless proceeds with his fundamental diagram computation without trying to quantify the uncertainty of the measurements he made.

The experimental issues

Not an instantaneous picture of the corridor!

- “From the fact that the movement of vehicles for each hour is very nearly uniform, we may [...] assume that during the 27 minutes the road was being photographed as many vehicles flowed on as flowed off the road ; **therefore, the continuous picture made up of the aerial photographs may be taken as substantially that which would be secured were it possible to take at a single instant a photograph of the traffic of the entire road**”.

Not an instantaneous picture of the whole corridor, but Johnson assumes it nonetheless with this rather questionable argument.

The experimental issues

A missed opportunity to derive a meaningful macroscopic fundamental diagram from the collected data

- Johnson derives two “macroscopic” variables:
 - The rate of flow (also called “discharge per hour”)
 - The (spatial) density (called “traffic density”, or “number of vehicles in each quarter of a mile”)
- The “velocity” used in his formula is ambiguous: “the general formula for the number of vehicles passing a given point at a given velocity”
 - Based on the individual velocity of vehicles, tracked between two successive exposures

Johnson mixes two scales of measurements (individual and averages) without clear definitions (especially of velocity). The lack of clear definitions leads to the formula he proposes.

Formal remarks on Johnson's paper

What would a wise PhD advisor say?

“When preparing a paper pay special attention to:

- 1. Introduction*
- 2. Figures*
- 3. References*
- 4. Conclusion”*

Intro

No presentation of the structure of the paper

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MARYLAND AERIAL SURVEY OF HIGHWAY TRAFFIC BETWEEN BALTIMORE AND WASHINGTON
A. N. JOHNSON
Dean, Engineering College, University of Maryland
On July 4, 1927, the State Roads Commission of Maryland had an aerial traffic survey made of the road between Baltimore and Washington.
For this purpose there were engaged the services of the Chesapeake Aircraft Company of Baltimore who made a series of photographs taken at an altitude of about 3,600 feet. The resulting photographs were of a scale of approximately 200 feet to the inch. These were subsequently enlarged to a scale of about 115 feet to the inch. The distance covered by the photographs, from the Baltimore City line to the Washington line, was very nearly 29 miles; 127 exposures were taken, each exposure being overlapped by the succeeding exposure. Owing to various causes, the scale of the photographs was not uniform, as did the amount of overlap.
During which photographs were taken was between 4:30 and 5 P.M., this hour being likely to show a large amount of traffic and to insure good photographs.
Photographic record thus secured, traffic counts were taken at the following stations: one near the Baltimore City line; one at College Park, a few miles from the Baltimore-Washington Road; one at the Washington line. Between these last two counting stations, as the Baltimore-Washington Road; thus, on road there was the additional traffic due to the highway.
At each of these stations there were two observers, one counting the south bound traffic during the period from 4:30 to 5 P.M., the other counting the north bound traffic during the period from 5:00 to 5:30 P.M. At the traffic stations noted the traffic at which varying rates per hour were calculated, and the results were fitted with white tops by stretching a sheet of paper over the map of the road.
The report of the writer is a description of the aerial traffic survey made by the State Roads Commission of Maryland on July 4, 1927. The report briefly outlined the organization, but as the studies had not then been completed, no conclusions were offered. In the present paper such studies as have been made are reported, together with a re-examination of the data of this investigation given in the Proceedings of the seventh annual meeting of the Highway Research Board.

No motivation of the paper

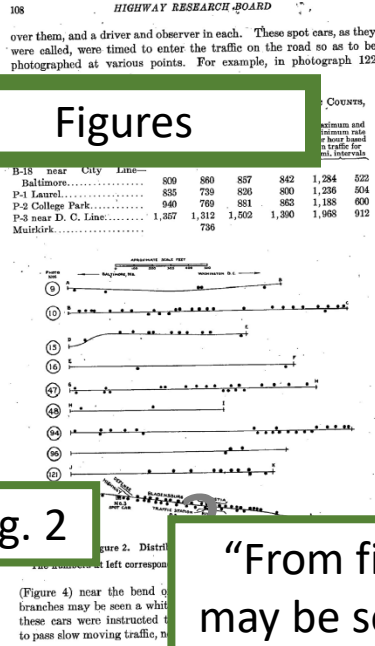
Fig. 5

Fig. 2

"From fig 5 may be seen"

"We will again refer to fig 2."

Figures



References

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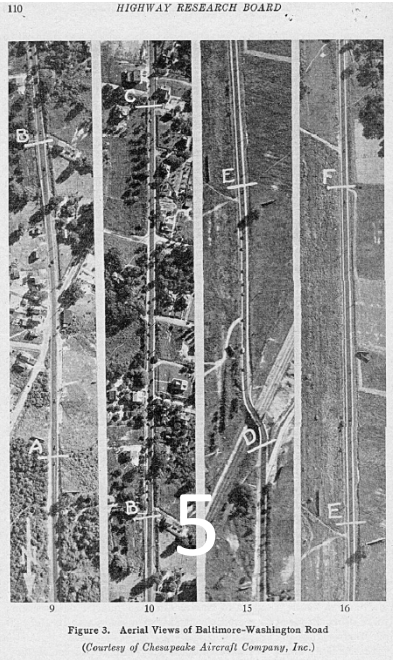
JOHNSON—AERIAL TRAFFIC SURVEY

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From the fact that the movement of vehicles for each hour is very nearly uniform, we may with sufficient accuracy for this discussion assume that during the 27 minutes the road was being photographed as many vehicles flowed on as flowed off the road; therefore, the continuous picture made up of aerial photographs may be taken as substantially that which would be secured were it possible to take at a single instant a photograph of the traffic of the entire road. Such a picture of the traffic was secured. To do this, the first step was to choose the portion of each photograph which was to be used. As the amount of overlap was not always uniform, it was necessary to select a longer section on some photographs than on others. This is illustrated by references to Figures 2, 3 and 4, where the numbers in the circles at the side are the same as for the corresponding photographs, which were numbered consecutively from 1 to 127. It is seen from photograph 9, Figure 3, the portion from A to B was chosen; the dots in Figure 2 indicate the location of the vehicles in that portion of the photograph. On photograph 10, Figure 3, point B coincides with B in 9, and the section chosen extended to C, and so on. Only a few of these photographs are shown in the figures, but they are sufficient for illustrative purposes.

From the charts, thus prepared, a graphic representation of the distribution of the traffic becomes apparent. To reduce this to a sketch that could be comprehended at a glance, a diagram was made that showed the number of vehicles in a quarter of a mile, as illustrated in Figure 5. But a glance at this figure is sufficient to disclose how uneven was the distribution of traffic. In some quarter mile sections there is but one or even no vehicles, and nearby there may be 15 or 20 per quarter mile.

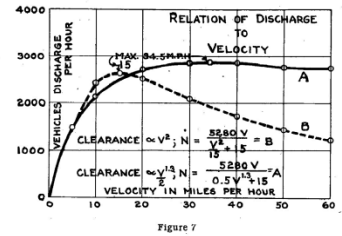
From Figure 5 may be seen that the average number of vehicles per quarter mile is about 7. At a speed of 25 to 30 miles per hour, 7 vehicles,



Only reference: a self-citation!

Only reference: inside text, no reference list

velocity varied as the square. Where the velocity varies as the square, it is noted that maximum discharge, about 2,000 vehicles per hour, occurs at a speed of 15 miles per hour, and that for higher speeds the curve turns down rather sharply, whereas, if we assume the clearance varied as found for curve A, the maximum is about 2,800 and the curve is more nearly flat for velocities from 20 to 50 miles per hour, that is for these velocities the number discharged per hour does not vary greatly. According to these figures then at 30 to 40 miles per hour, with vehicles going in each direction, on a two-lane road, there should be a total discharge of about 5,600 per hour. For short intervals of time, such a rate



of discharge did actually occur. But so far as the writer has been able to find, there is no record of any hourly discharge of a single line of vehicle exceeding 2,000. The maximum reported for the Holland Tunnel traffic was just under this amount, about 1,900.

A conclusion to be drawn from the aerial traffic survey is the importance of any regulation which will tend to greater uniformity in the distribution of traffic and that whatever will help to do this will to that extent increase the efficient use of the road.

Inasmuch as the Baltimore-Washington Road is to be widened to 40 feet, a section of this increased width from 20 feet to 40 feet having already been completed, the comparison between another aerial survey of the traffic and this one would doubtless reveal much interesting and valuable information.

Concl.

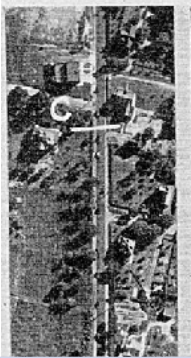
* See Engineering News-Record for December 27, 1928, p. 947.

4

Aftermath

The 60 first years of traffic measurement

Aftermath of Johnson's aerial survey



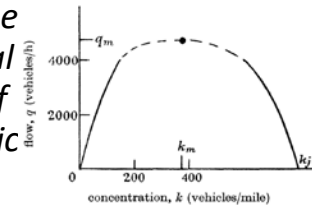
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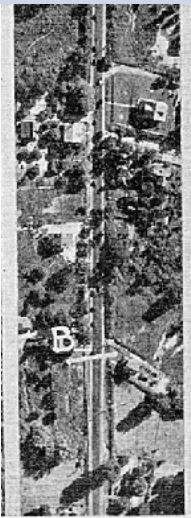
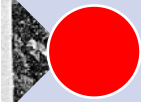
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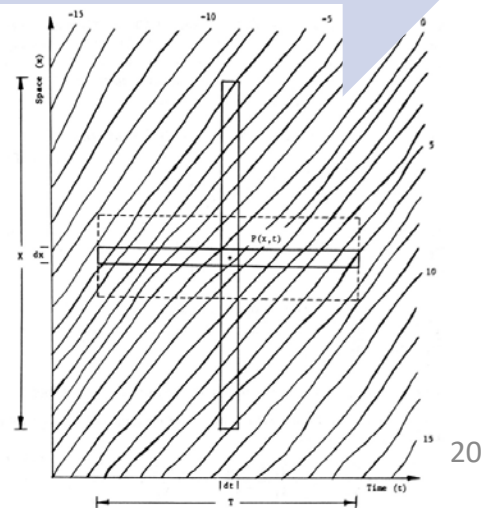


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1950: first
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Lighthill &
Whitham,
Richards,
1955-1956:
*On
Kinematic
Waves. A
Theory of
Traffic Flow
on Long
Crowded
Roads*



Considering traffic as a stochastic series

- The “distribution of traffic”, “illustrating how inefficiently the traffic made use of the roadway”, as stated by Johnson, fueled, at least for a part, the use of probability theory to describe traffic:
 - Kinzer followed by Adams (1934): *Road traffic considered as a random series*, in which the flow of traffic is identified to a Poisson process. The assumption is then used to solve operational problems (traffic flow forecast, left-turn signal timing at an intersection...)
 - Stochastic considerations by Greenshields:
 - Greenshields, Schapiro & Ericksen (1942), *Traffic performance at urban street intersections*
 - “[The Poisson theory allows to solve] traffic problems that otherwise would be very difficult, if not impossible, to solve”
 - Greenshields & Weida (1954), *Statistics with applications to highway traffic*
 - ...

Paving the way to a road's “capacity” and flow-concentration relationship

- Even in Johnson's work, the aftermath of his aerial observations is limited.
- A few years later (1931), Johnson gives a definition of capacity, but **derived from roadside observation**. His definition is a two-threshold capacity relying both on:
 - the number of vehicles *on the highway* (i.e., the density !)
 - the number of vehicles *passing a given point* (i.e., the flow !)
- “congestion”: “the number of vehicles reaches a total great enough to fill the road and make turning out impracticable”
- “working capacity or free-moving capacity of the highway”: “a point at which some vehicles will be delayed because they are immediately unable to pass”
- “ultimate capacity of the highway”: “a point is reached where the total volume is at the maximum”
- afterwards: “the number of vehicles on the highway becomes so great as seriously to interfere with their movement, and the number passing a given point during a given time begins to decrease”

Greenshields (1934-1935)

Capacity, flow-speed and density-speed relationships

- point observation of traffic using a motorized spinning picture camera
- uncertainty for the “congestion” domain beyond the “capacity”: does the flow increase, stagnate or decrease?
- terminology ambiguity: “density” designates both the flow and the spatial density

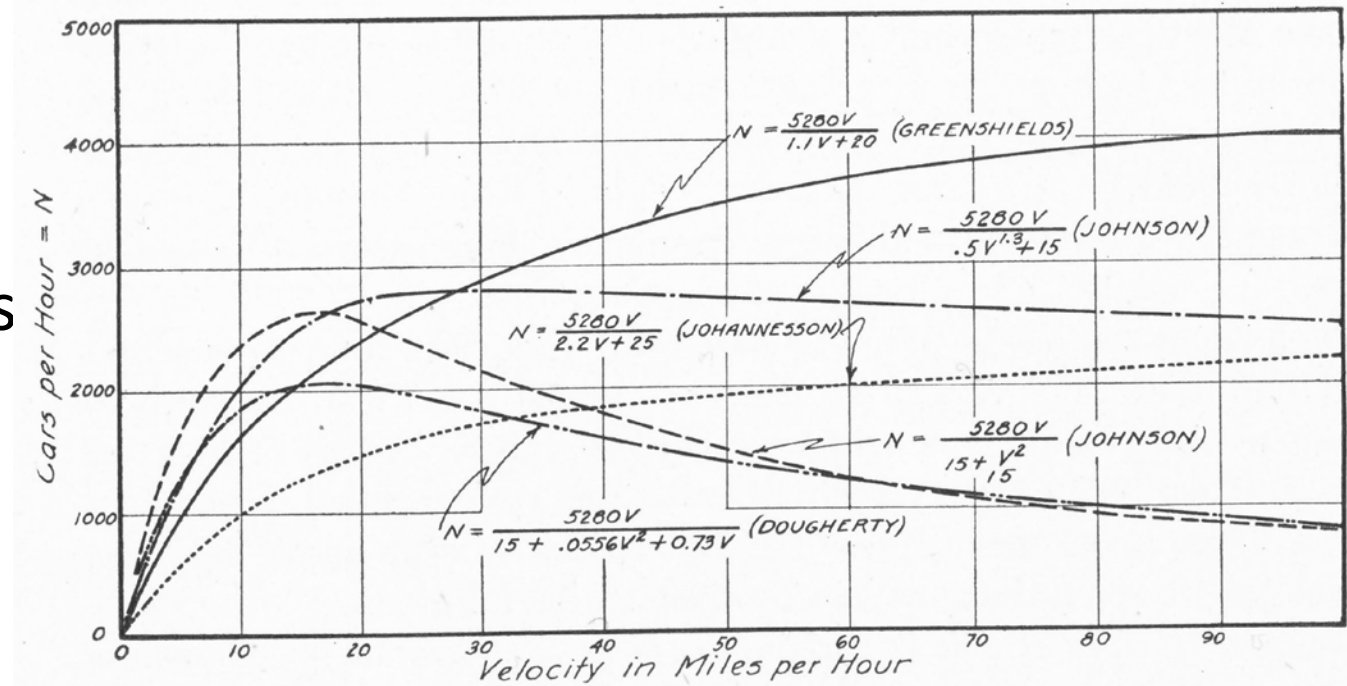


Figure 7. Graphic Comparison of Formulas for Determining the Relation Between the Number of Vehicles Passing a Given Point and Their Rates of Speed.

Greenshields (1934-1935)

Capacity, flow-speed and density-speed relationships

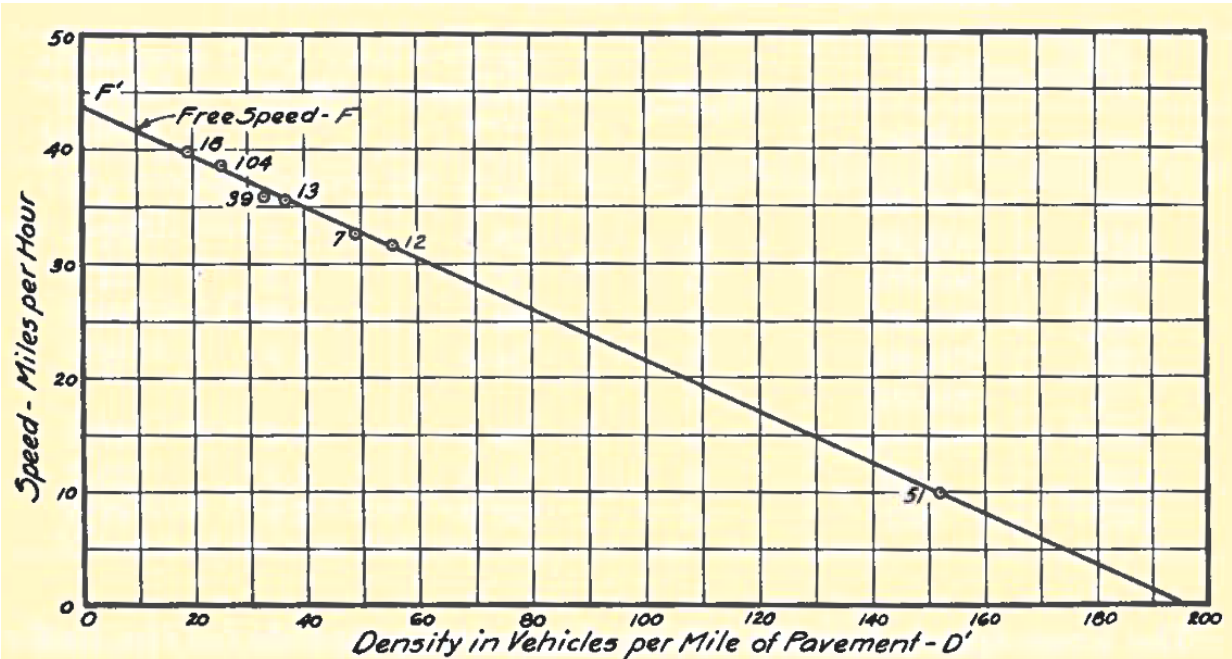


Figure 5. Speed in Miles Per Hour Corresponding to a Given Average Density in Vehicles per Mile of Pavement.

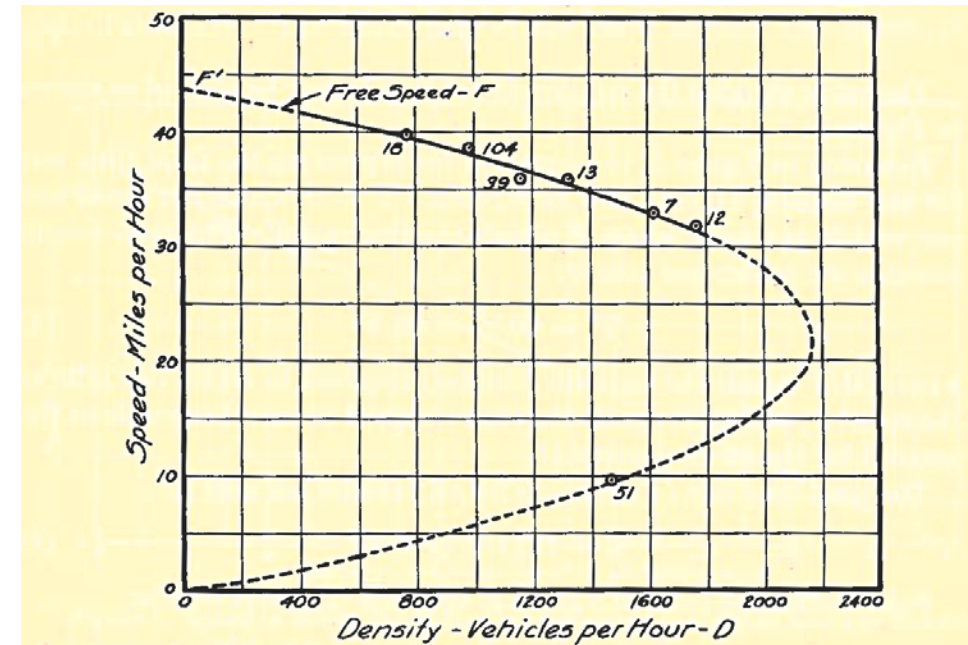


Figure 6. Speed in Miles per Hour Corresponding to a Given Density in Vehicles per Hour on a Two-lane Highway.

Aftermath of traffic variables

- 1952: Wardrop formalizes the underlying concepts of Johnson and Greenshields works:
 - the $q = k \times v$ relationship
 - the definitions of time-mean and space-mean speeds
- 1954-1956: Lighthill & Whitham, Richards, derive the hypothetical “convex” $q - k$ curve based on empirical evidence in extremal conditions (“free-flow” and “congestion”) and Rolle’s theorem for “long and crowded roads”.
- 1963: Edie clears out the ambiguity of harmonic and arithmetical averaging based on how traffic is measured (space or time), and generalizes the definitions of $q - k - v$.

Conclusion

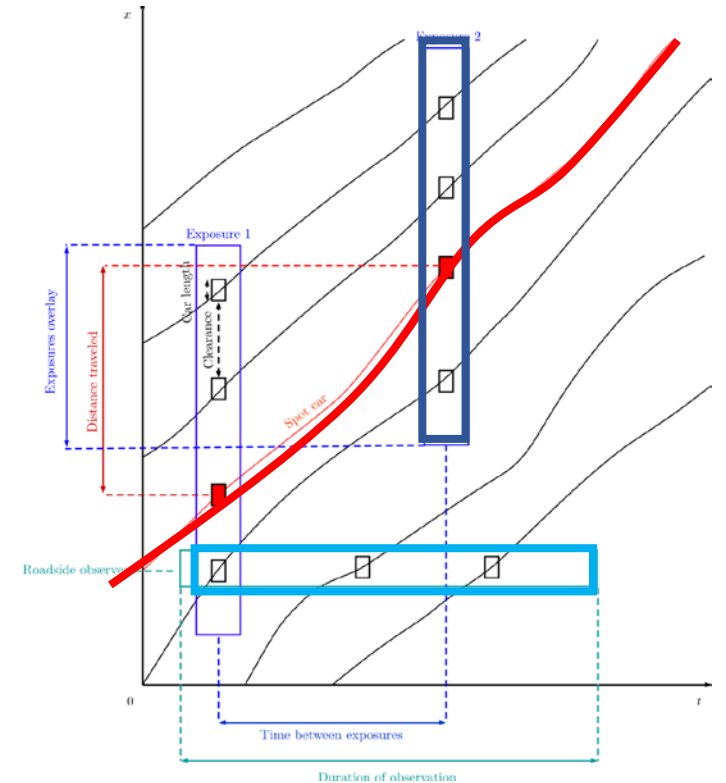
Johnson's heritage:

1- aerial, FCD and fixed observations of traffic

A bright mind with exceptional experimental design capabilities!

He was the first to understand that three ways of observing traffic coexist:

- **Aerial surveys** have remained a not-so-infrequent way of observing highways:
 - Treiterer & Myers, NGSim, Hoogendoorn & al., ...
- **Floating Car Data** technology are now widely used (GPS, Galileo, ...)
- **Local measurement of flow data**, since more than a century
 - Local counts by human observers
 - Since the 70s, loops

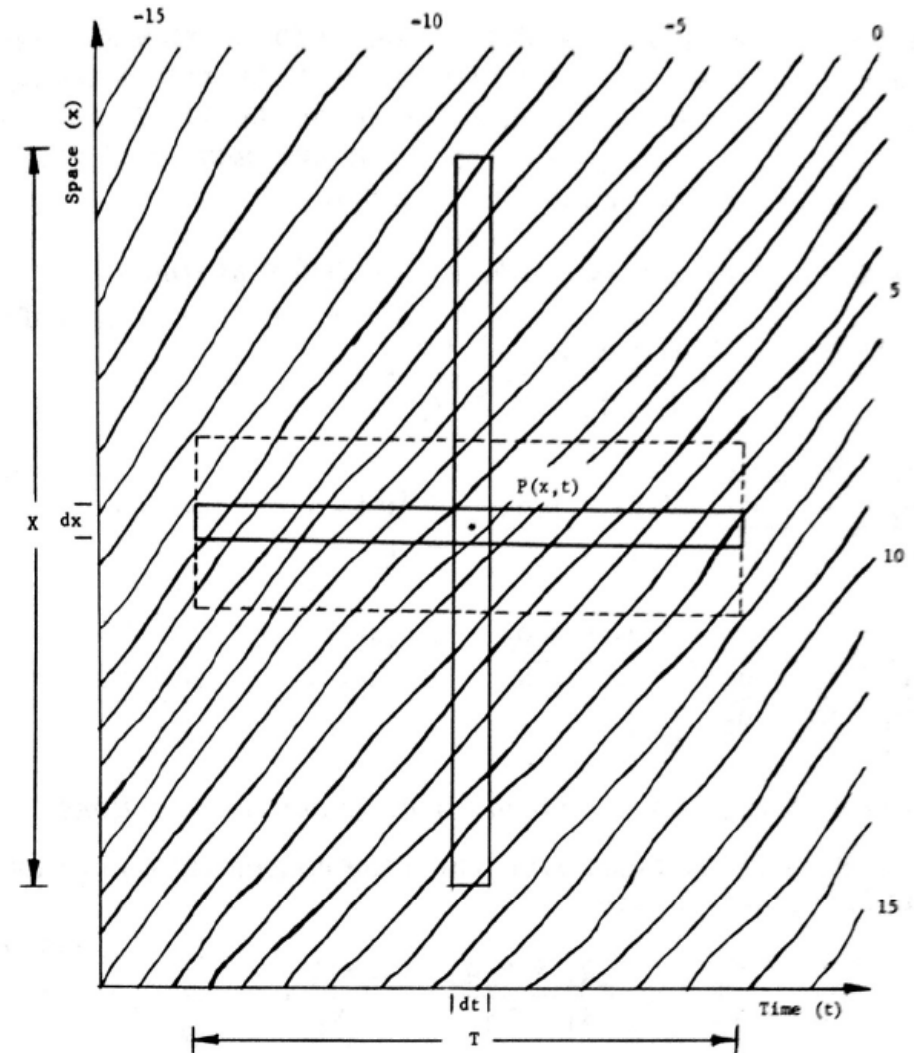


Conclusion

Johnson's heritage:

2- The spatial nature of density

- Unfortunately his main idea (spatial nature of density) had to wait until Eddie (1963) to be re-discovered a first time



Conclusion

Take-home message

- Document and share your data
- Publish your research
- Read (and cite) the others' work, **including “classic” papers!**

Some references by Arthur N. Johnson

- A.N. Johnson & al. Road traffic census. In *First annual report of the Illinois Highway Commission for the year 1906*, pp 22-29, 1907.
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 - Some Theoretical Aspects of Road Traffic Research. *Proceedings of the Institution of Civil Engineers*, 1-3, pp 325-362, 1952.

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Slide	Illustration credits
1	A.N. Johnson portrait : Institute of Transportation Engineers, 2018, https://www.ite.org/aboutite/honorarymembers/JohnsonAN.asp
3	“Traffic record”: Johnson, 1906 Aerial view: Johnson, 1929
4	Aerial view: Johnson, 1929 Greenshields’ picture: Greenshields, 1934 “Highway Capacity Manual” cover: HCM, 1950 Fundamental diagram: Lighthill & Whitham, 1955 Space-time diagram: Edie, 1963
10	Johnson, 1929
11	Johnson, 1929
12	Johnson, 1929
18	Johnson, 1929
20	Same as slide 4
23	Greenshields, 1934
24	Greenshields, 1935
27	Edie, 1963