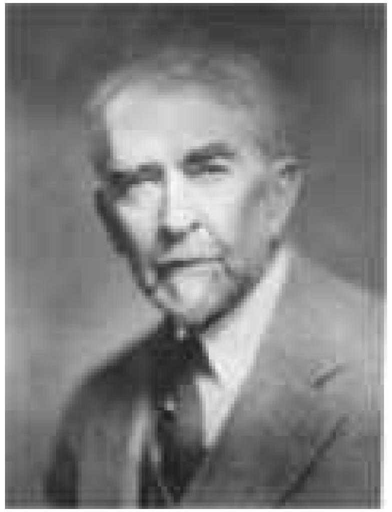


Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington

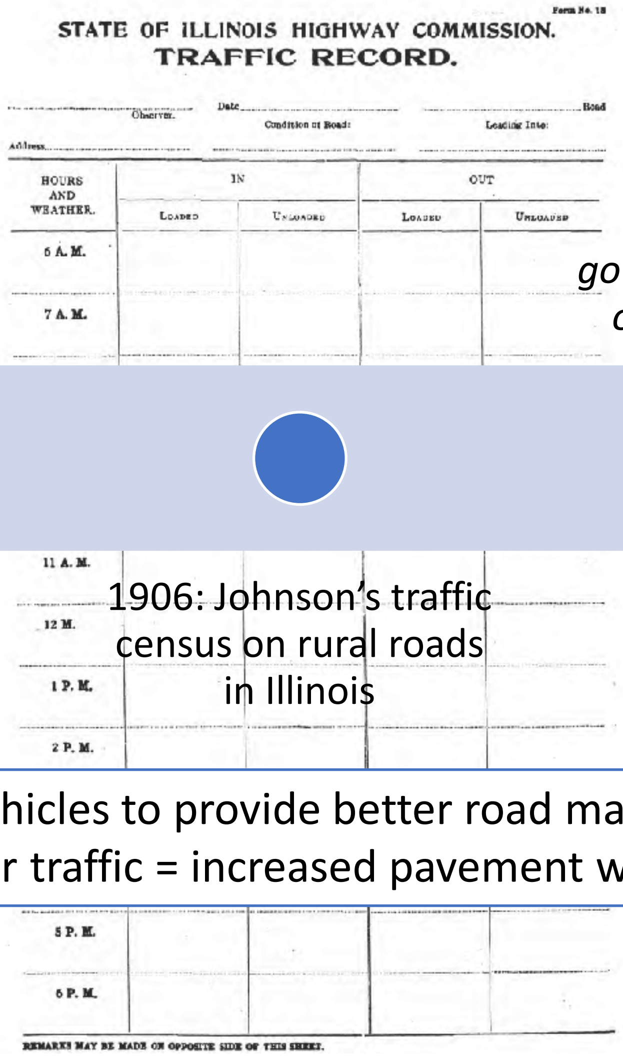
Arthur N. Johnson (1870-1940)

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

Luc Charansonney (Ville de Paris)
Christine Buisson (IFSTTAR/ENTPE)

1
The historical context

The 60 first years of traffic measurement
Towards Johnson’s aerial survey



Form No. 18

STATE OF ILLINOIS HIGHWAY COMMISSION.
TRAFFIC RECORD.

Observer. Date. Road
Condition of Road: Leading Into:
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.

1844: first French traffic census

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

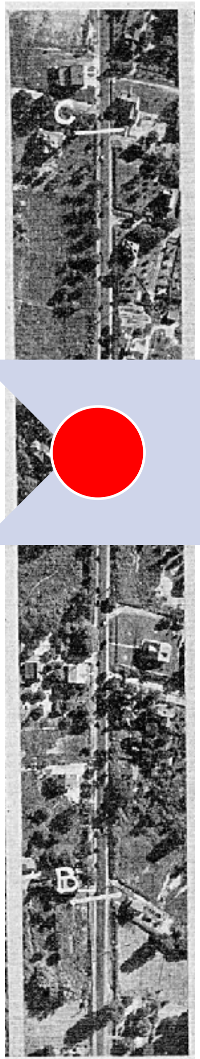
1926: *Elements governing the growth of highway traffic*

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

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

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

The 60 first years of traffic measurement
Aftermath of Johnson's aerial survey



Johnson, 1931: *Traffic Capacity*

Johnson, 1933: *Notes on Traffic Speed*

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

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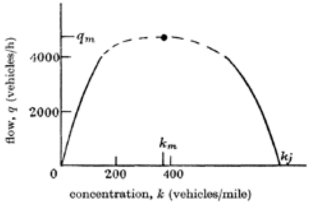
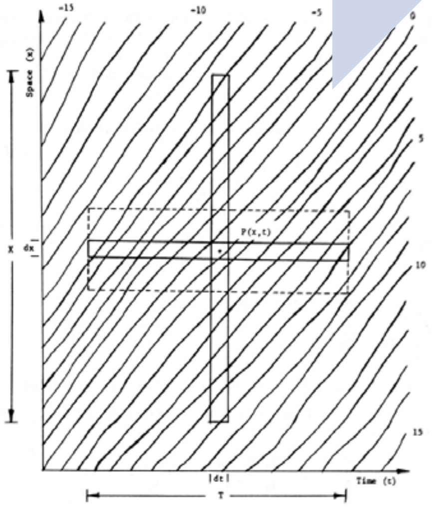
1950: first edition of the *Highway Capacity Manual* (HCM)

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

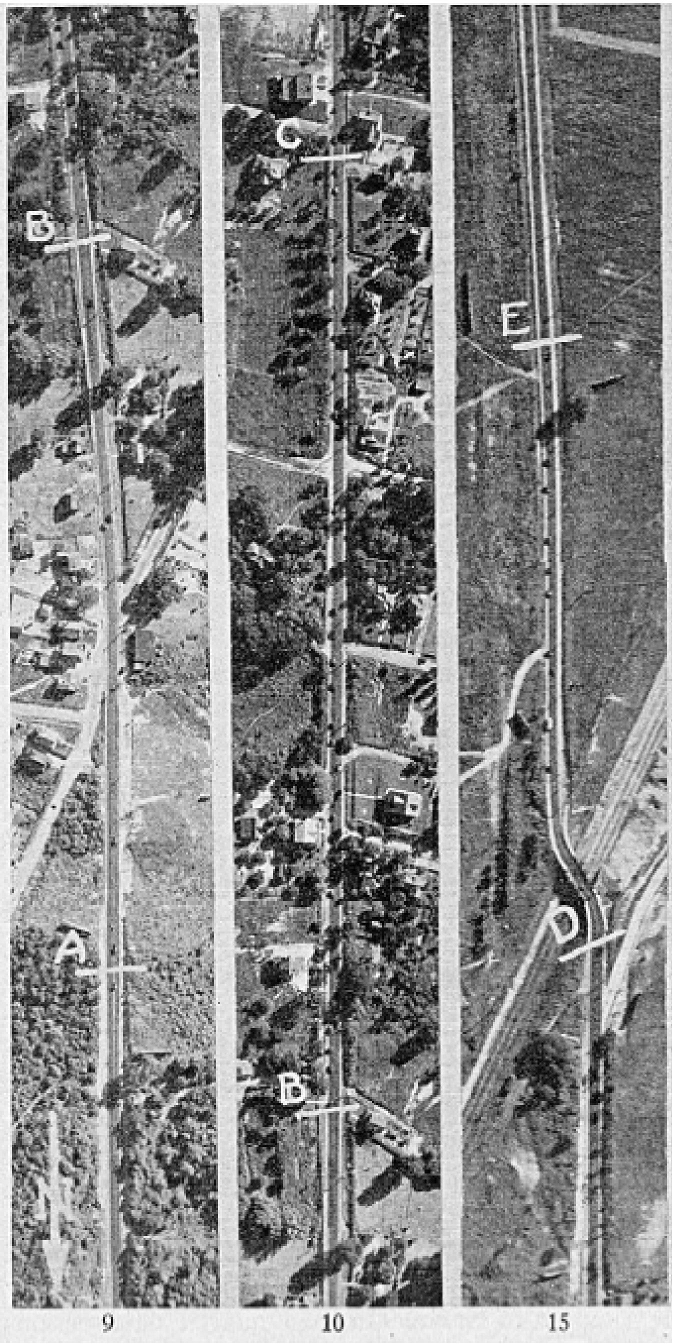


Lighthill & Whitham, Richards, 1955-1956: *On Kinematic Waves. A Theory of Traffic Flow on Long Crowded Roads*



Edie, 1963: *Discussion of traffic stream measurements and definitions*

2
The content of Johnson's paper



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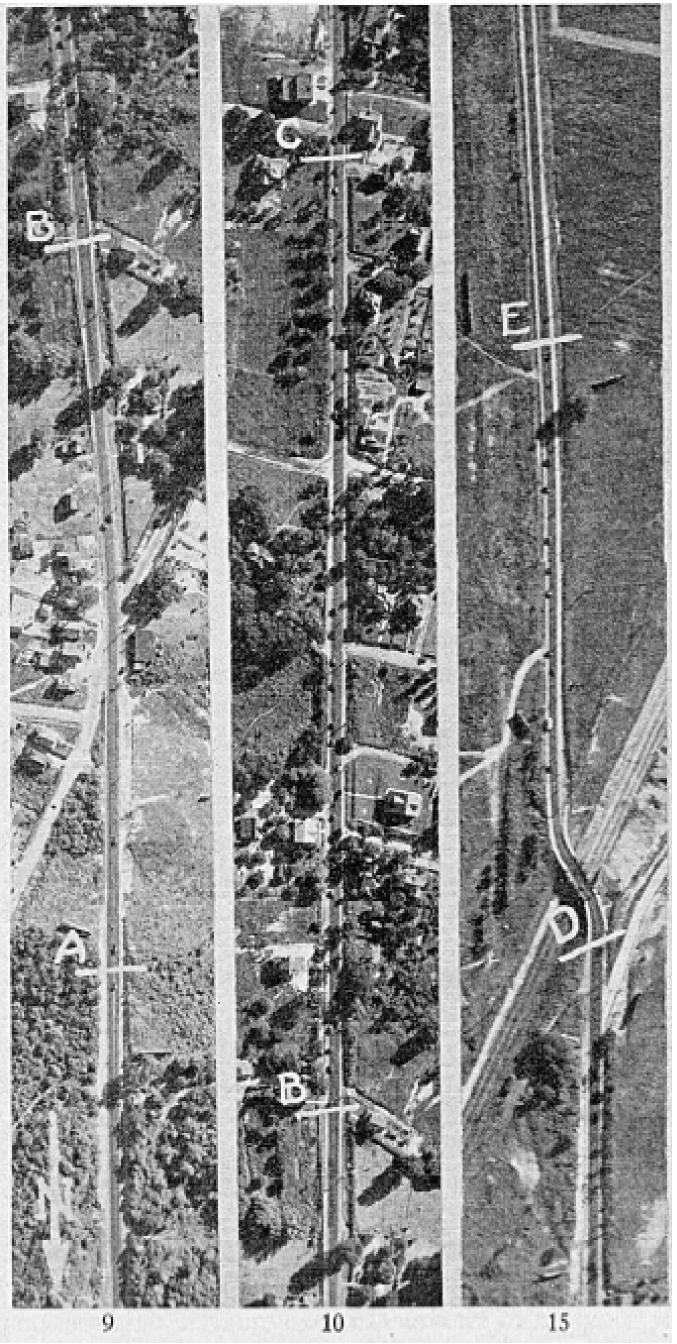

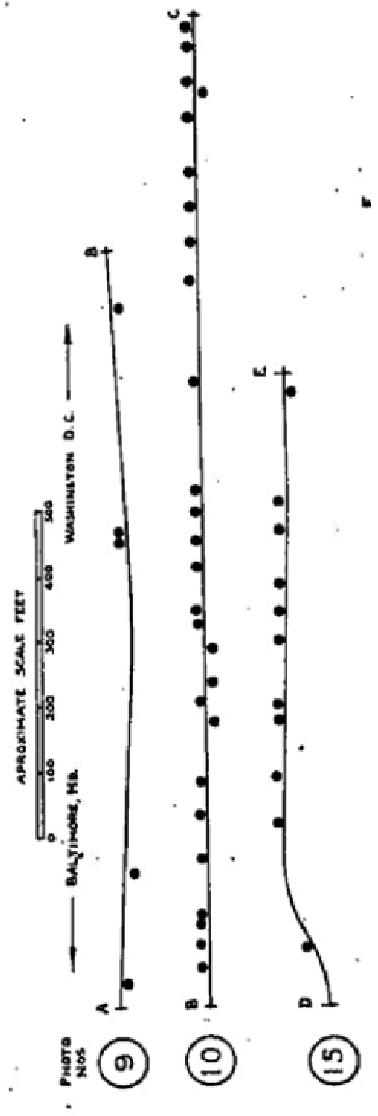

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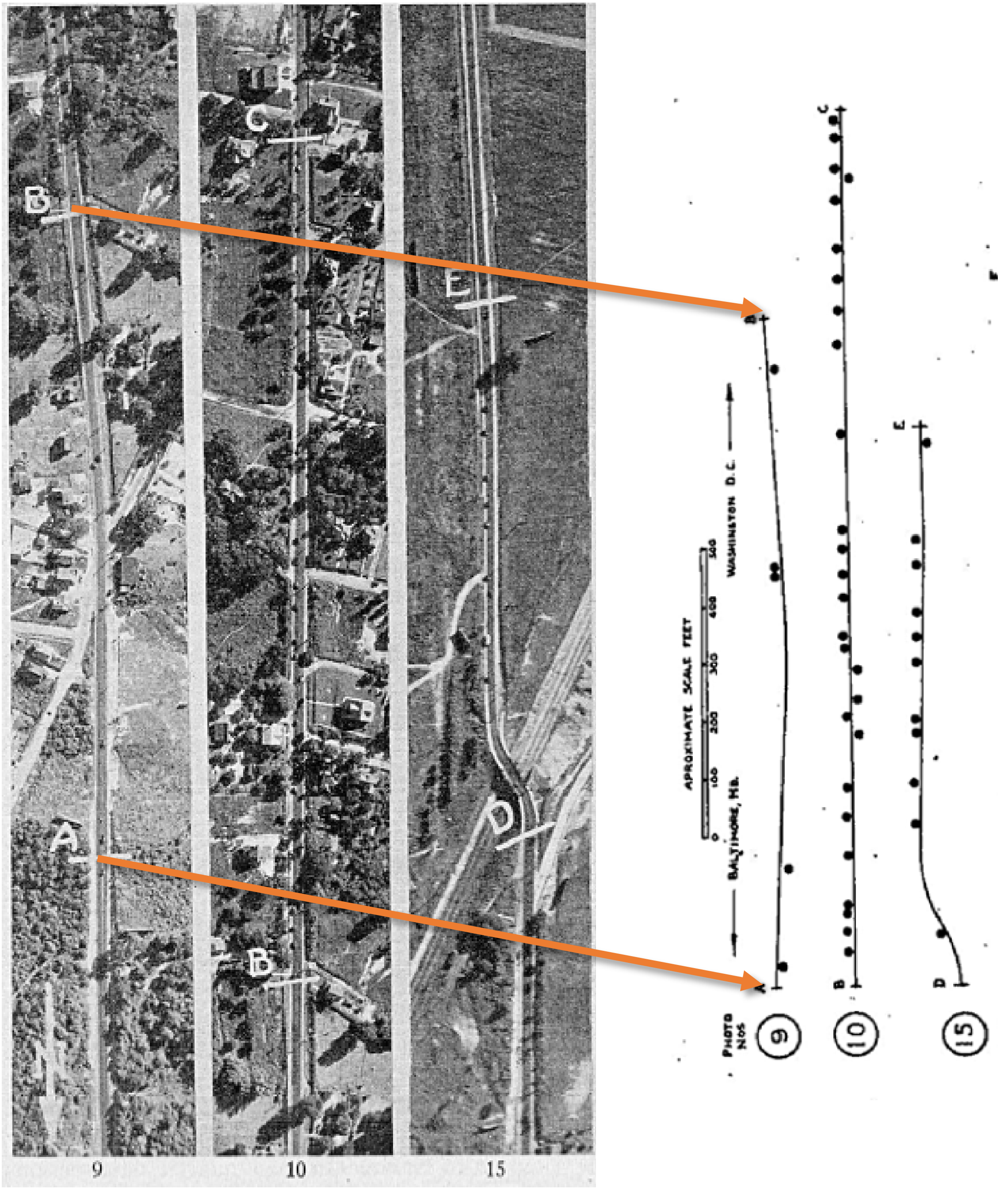

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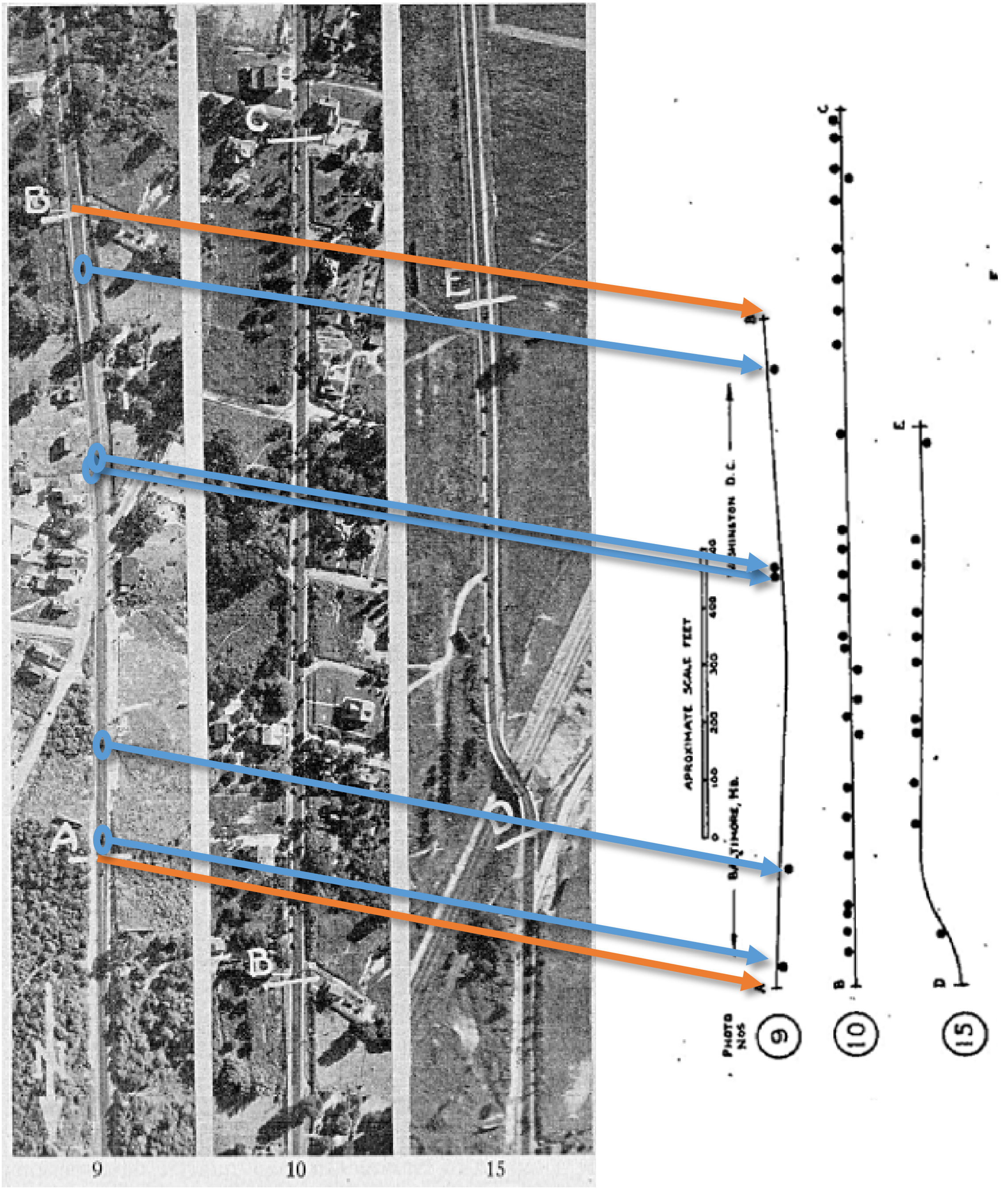
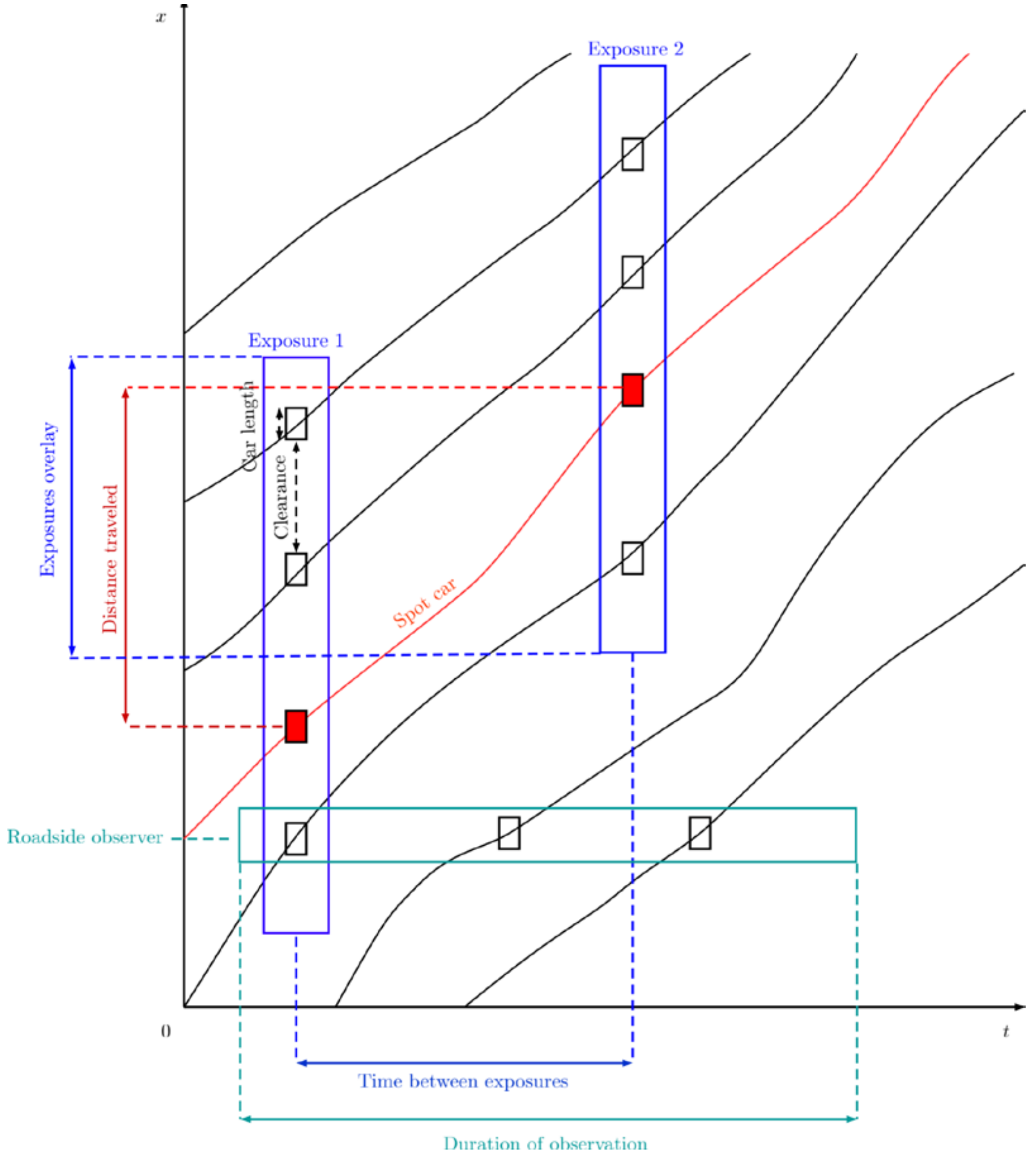


The experimental design



- **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

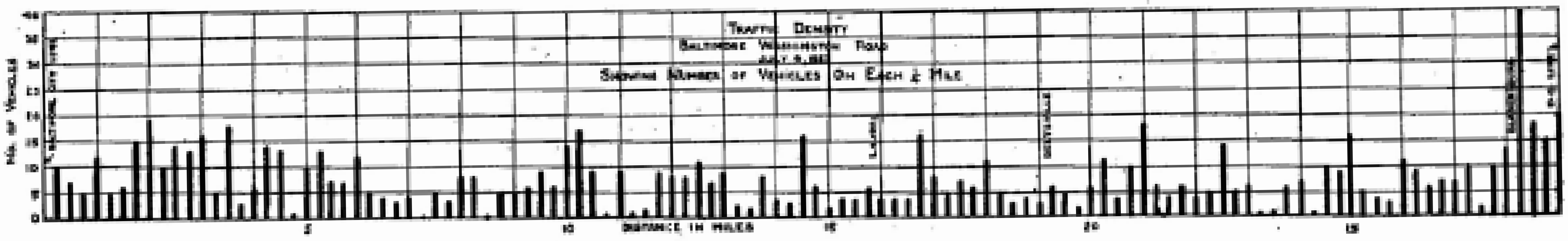


Figure 5

- “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

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

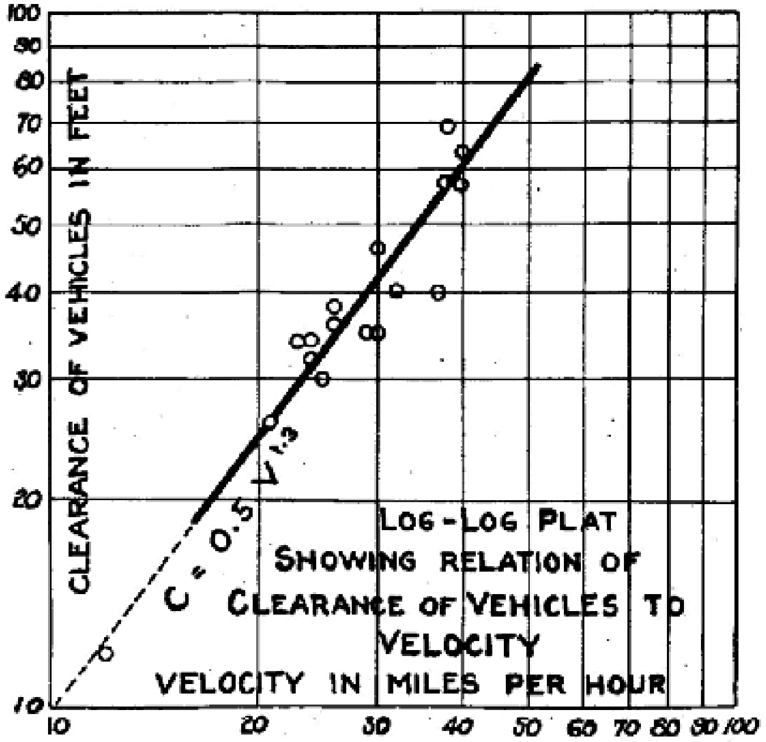
If you’re not used to those (stupid) units, 5,280 simply is the miles/feet ratio

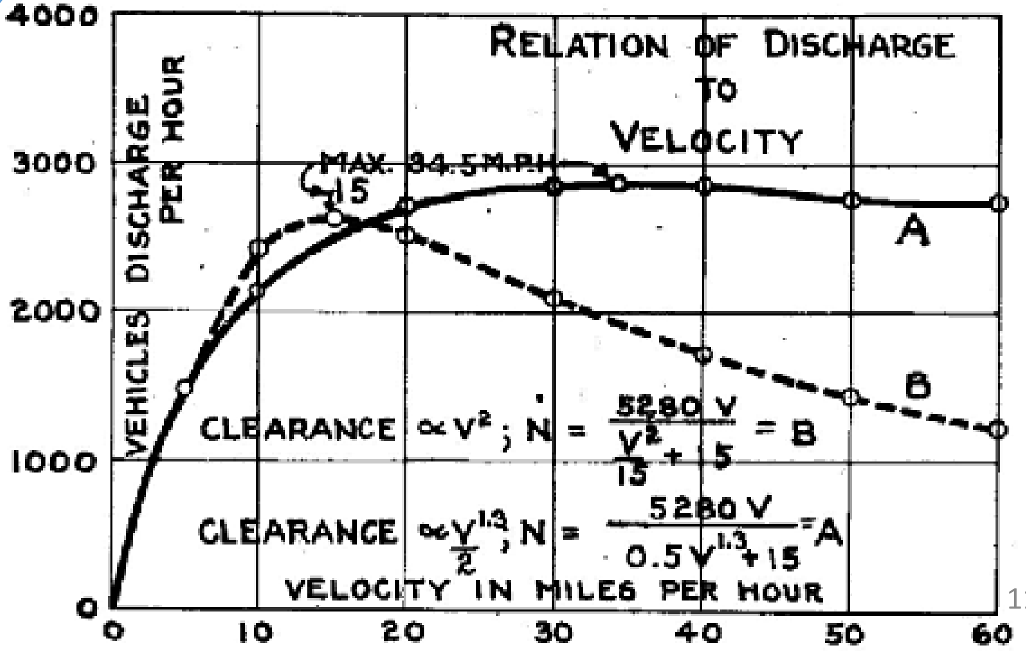
- D : distance between cars

$$D = C + car\ length$$

- C : clearance

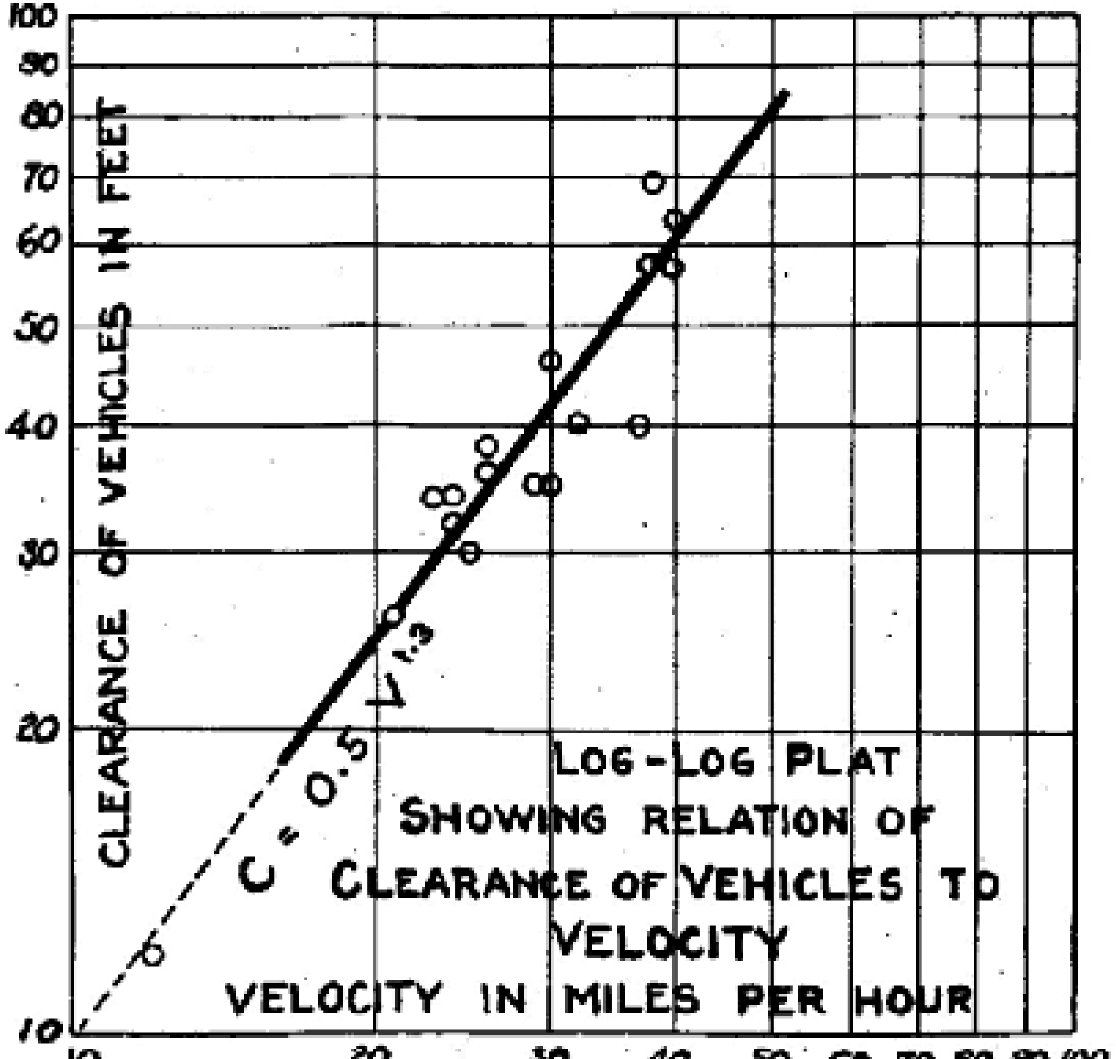
$$C = 0.5 \times V^{1.3}$$

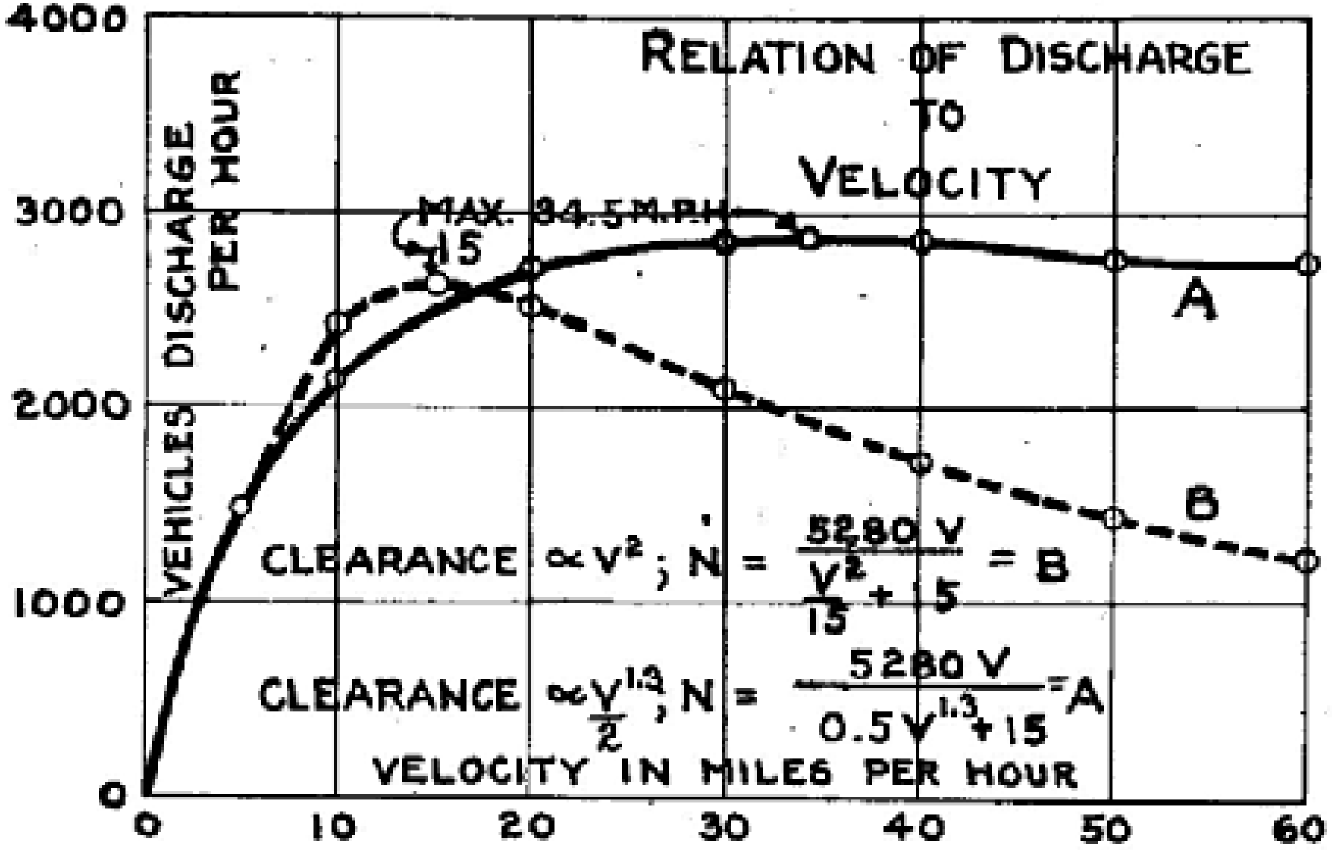




Results

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

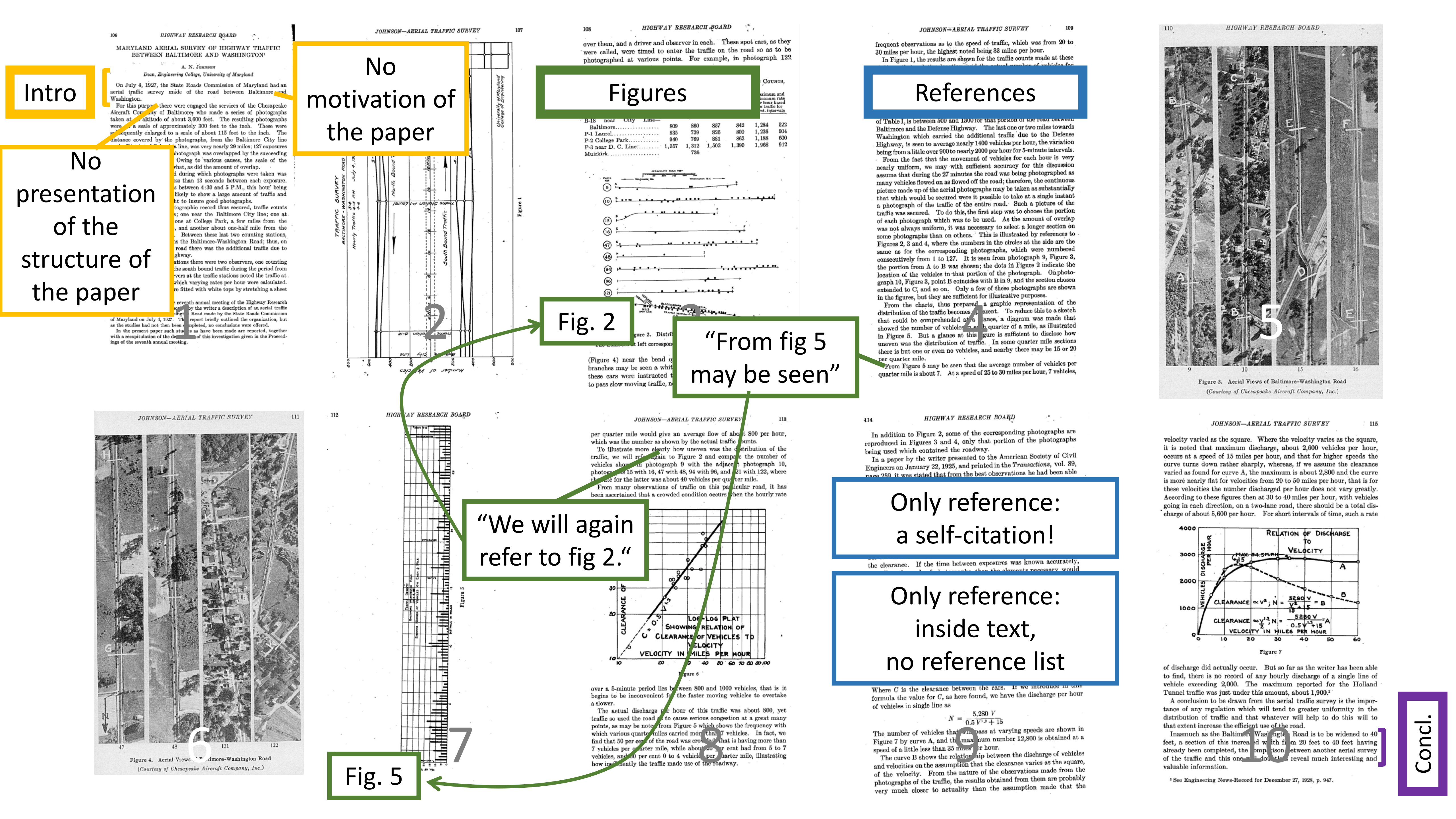
Johnson mixes two scales of measurements (individual and averages) without clear definitions (especially of velocity). The lack of clear definitions leads to the formula he proposes.

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
No motivation of the paper
Figures
References
Fig. 2
"From fig 5 may be seen"
"We will again refer to fig 2."
Fig. 5
Only reference: a self-citation!
Only reference: inside text, no reference list
Concl.
1
2
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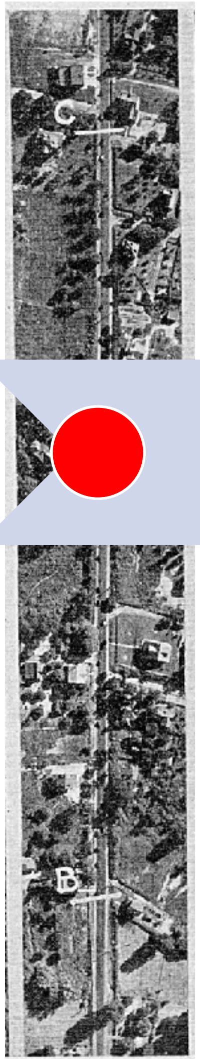
4
Aftermath

The 60 first years of traffic measurement
Aftermath of Johnson's aerial survey



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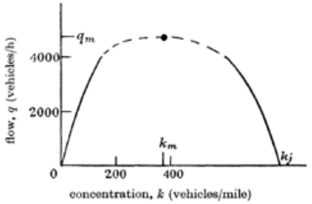

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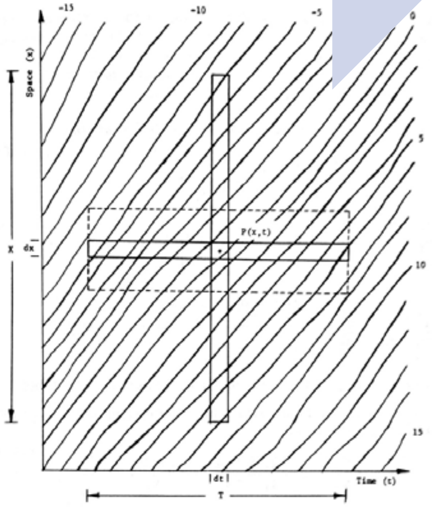


Edie, 1963: *Discussion of traffic stream measurements and definitions*

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

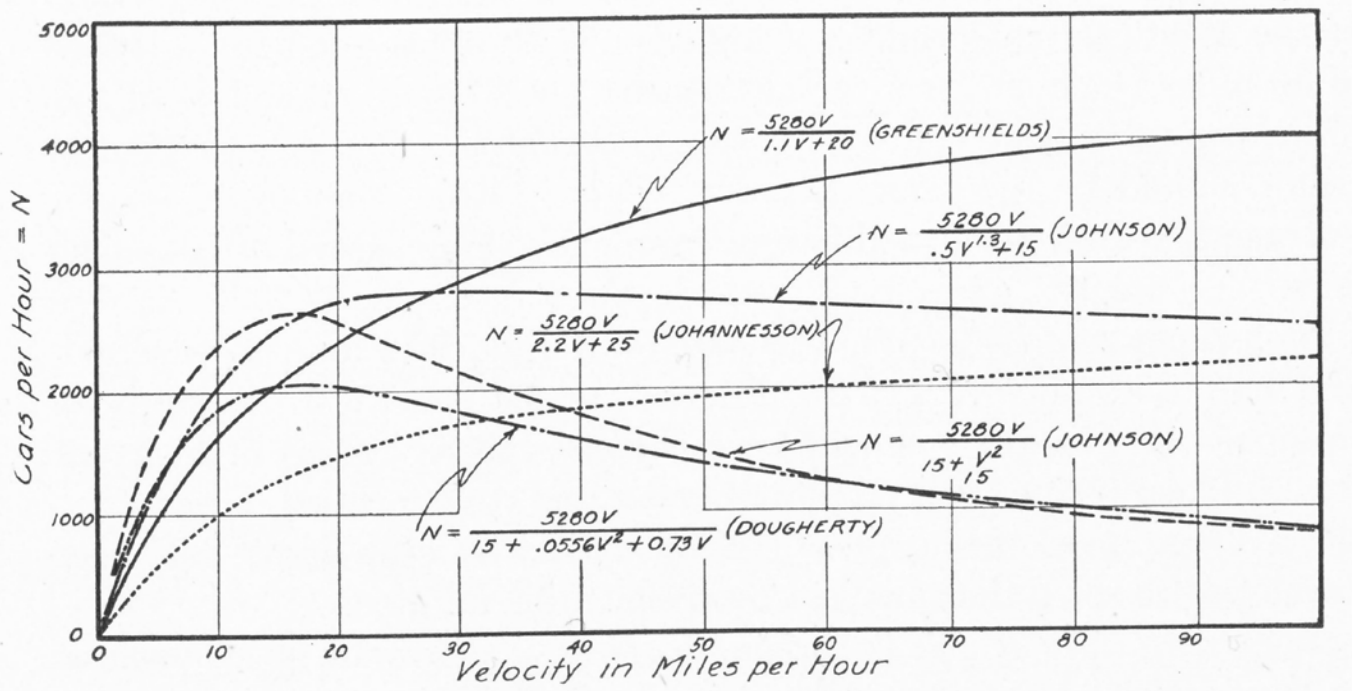


Figure 7. Graphic Comparison of Formulas for Determining the Relation Between the Number of Vehicles Passing a Given Point and Their Rates of Speed.

Greenshields (1934-1935)
Capacity, flow-speed and density-speed relationships

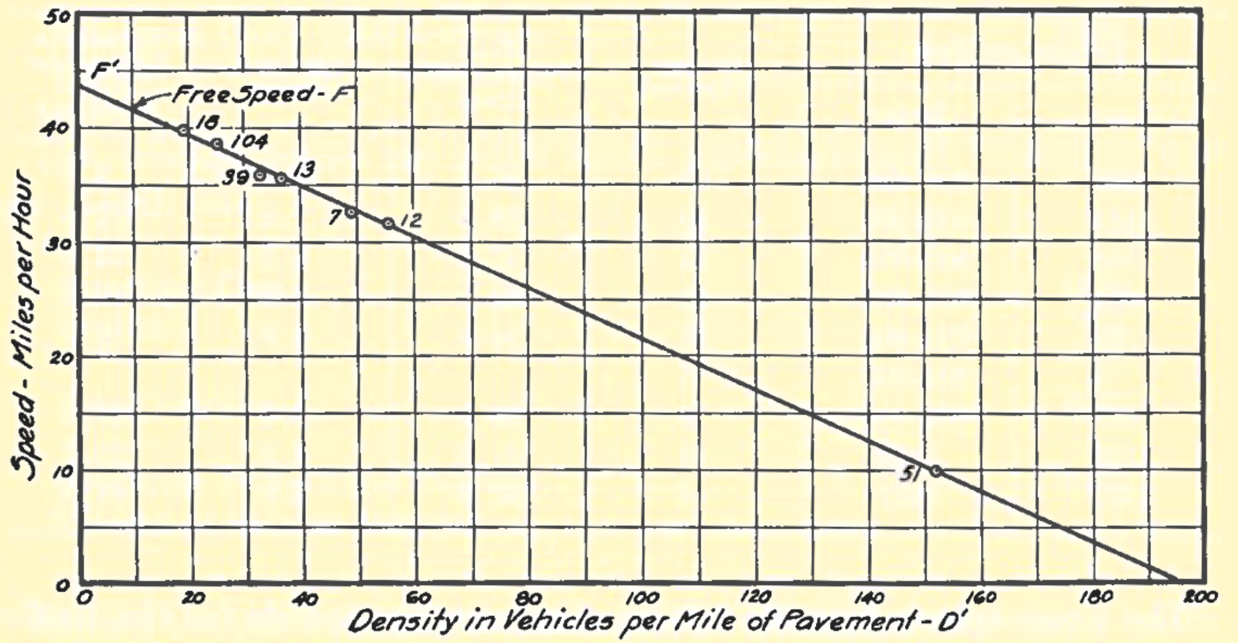


Figure 5. Speed in Miles Per Hour Corresponding to a Given Average Density in Vehicles per Mile of Pavement.

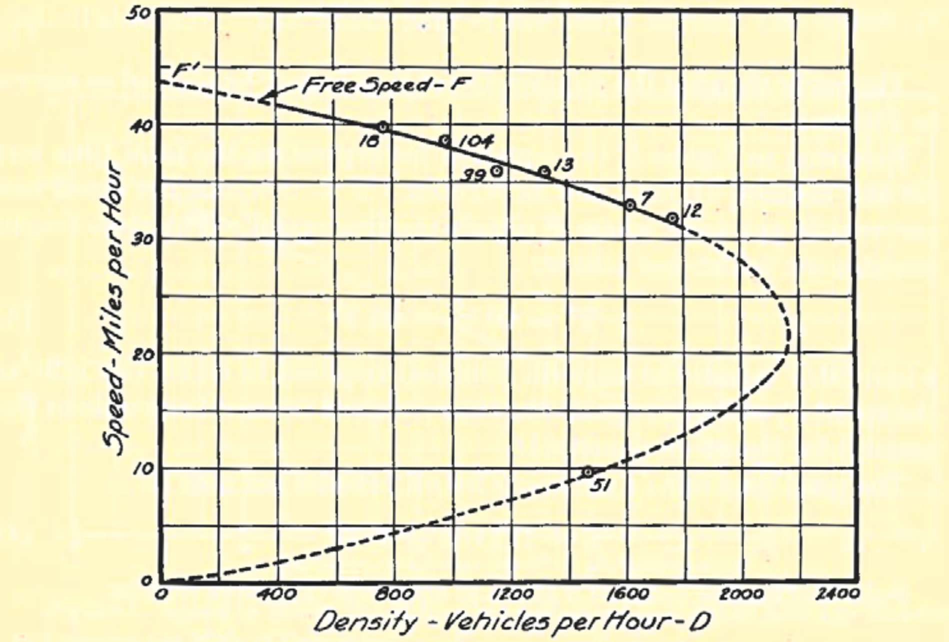


Figure 6. Speed in Miles per Hour Corresponding to a Given Density in Vehicles per Hour on a Two-lane Highway.

Aftermath of traffic variables

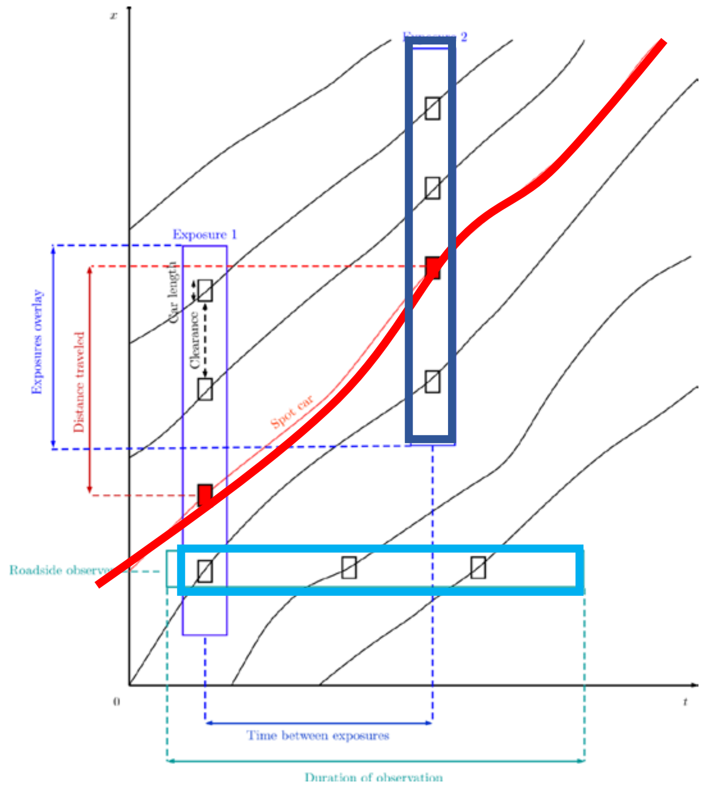
- 1952: Wardrop formalizes the underlying concepts of Johnson and Greenshields works:
  - the $q = k \times v$ relationship
  - the definitions of time-mean and space-mean speeds
- 1954-1956: Lighthill & Whitham, Richards, derive the hypothetical “convex” $q - k$ curve based on empirical evidence in 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!

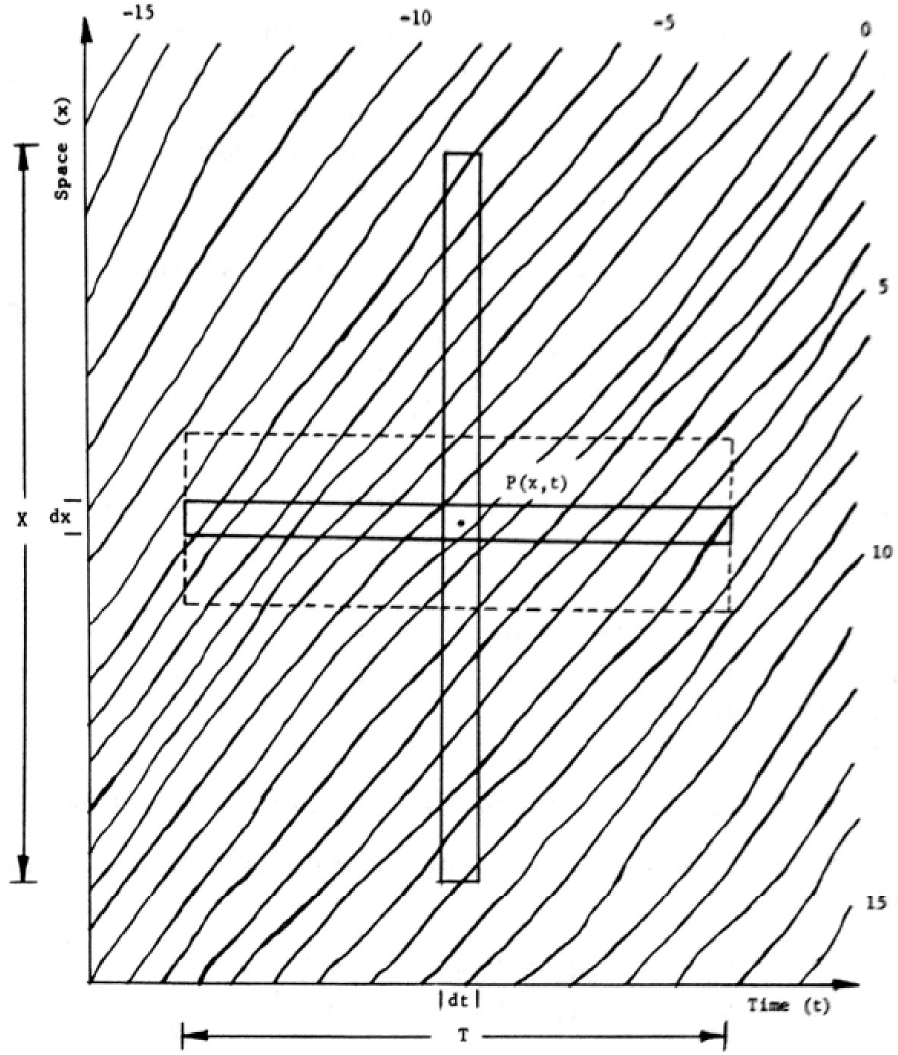
He was the first to understand that three ways of observing traffic coexist:

- **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.
- A.N. Johnson. Elements governing the growth of highway traffic. *Transactions of the American Society of Civil Engineers,* 89 (1), pp 259-267, 1926.
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  - Discussion of traffic stream measurements and definitions. In *Proceedings of the Second International Symposium on the Theory of Road Traffic Flow*, pp 139–154, 1963.
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  - On kinematic waves. I. Flood movement in long rivers. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 229-1178-, pp 281-316, 1955.
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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