
Supply Side Analysis & Verification of Ridership Forecasts: A Retrospective

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Leroy W. Demery, Jr. • Contributions by Michael D. Setty • April 15, 2005



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P.O. Box 6076
Vallejo, CA. 94591-6076
(707) 557-7563
(707) 557-6735 fax

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Abstract

Ridership carried by U.S. fixed-guideway transit projects opened from the mid-1980s typically fell short of levels forecast during early planning. Such forecasts failed to consider service-supply factors, or “practical” capacity as built. Disparity between forecast and observed ridership provides no grounds for conclusion that the forecast was “incorrect.” If the requisite service level was not provided, then the forecast was not tested. Using Sacramento’s light-rail starter system as an example, this paper demonstrates that the line, as built, was not capable of accommodating peak-period passenger volumes of the size implied by the early planning forecast of 50,000 passengers per weekday. The principal limiting factor, in this and other cases, was vehicle fleet size although train length and maximum service frequency limits are characteristic of light rail facilities. The paper summarizes research published a decade ago; transportation planners today have access to more data, greater analytical capability and lessons learned from the mid-1980s. One important example: transit consumers are evidently not willing to tolerate peak-hour crowding at levels once assumed by planners. Again, Sacramento offers clear and cogent proof, based on service-supply factors, that the LRT system “as built” could not carry the forecast 50,000 passengers per weekday, and that the “likely maximum” patronage was less than half the forecast. Acknowledgment of this fact may jeopardize the “forecaster bias” theory regarding new rail projects popular among some transport economists and academics.

Introduction

This ten-year retrospective on the research leading to the paper “Supply-Side Analysis and Verification of Ridership Forecast for Mass Transit Capital Projects” (*Journal of the American Planning Association*, 60, 3: 355-371) was inspired by a member of an online discussion list:

I challenge any one in this chat room to prove that VTA is meeting their federal ridership projections.

"VTA" is the Santa Clara Valley Transportation Authority, <http://www.vta.org> . The “challenge” referred to the ridership forecasts current at the time when the Guadalupe Corridor light rail (LRT) project was designated as the "Locally Preferred Alternative." The JAPA article was prepared in close collaboration with J. Wallace Higgins, a virtual co-author whose contributions were essential.

The person who issued the “challenge” probably used this phraseology as a (somewhat overblown) rhetorical point, and perhaps did not anticipate a serious response. Nonetheless, the author accepted, subject to one key caveat: that he would be entitled to claim "victory" upon presentation of proof that the "projections" were either A.) attained, or B.) are as a practical matter unattainable by the system in its existing ("as-built") configuration. The person who issued the “challenge” ignored this response.

It is disarmingly simple to prove – mathematically – that B.) above is true for a number of U.S. rail projects opened from the mid-1980s.

It is also simple to explain why this occurred: During early planning stages, ridership forecasts were prepared with inadequate reference – or no reference at all – to service-supply factors. In other words, the forecasts were prepared without considering the practical capacity of the lines “as built.” Transit planners and operators, however, have learned much since the 1980’s. The research outlined below was spurred by a citation to an early planning forecast for Sacramento’s initial LRT project. The narrative below therefore relates to Sacramento, but the methodology is not limited to that project.

1) 50,000 per day? That's Not Possible!

The initial edition of *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Cost* (Pickrell 1989) was published in October 1989. As the author perused a copy, the weekday ridership “forecast” for Sacramento almost leaped off the page; he mumbled out loud, in disbelief: “Fifty thousand per day? That’s not possible!”

Pickrell considered four heavy rail (HRT) and four LRT projects. The Sacramento forecast stood out as utterly unattainable. The “RT Metro” starter system, as built, was single track. The maximum service frequency was 15 minutes between trains, or four trains per hour. The maximum train length of four cars, although uncharacteristically generous for LRT using downtown streets for business center (CBD) access, permitted a maximum of just 16 vehicles per hour. This the Sacramento Regional Transit District (SRTD) could not provide back then, because the initial fleet size was not large enough. The maximum practical peak service supply was 12 vehicles per hour until SRTD procured additional vehicles. Much of the starter system was double-tracked during the 1990s and a third branch has been added, but 15 minutes remained the maximum service frequency away from the CBD at spring 2005.

An important fact downplayed by Pickrell and not noticed by the author: the 50,000-per-weekday forecast was based on a “20-year horizon.” In other words, the 1980 alternatives analysis (AA) anticipated 50,000 passengers per weekday by 2000 – subject to assumptions including a greatly expanded bus system, increased cost and limited supply of downtown parking, gasoline prices rising faster than inflation – and an appropriately-sized vehicle fleet. The 50,000-per-weekday forecast was therefore not appropriate for comparison with results on “opening day.” (Schumann 2005).

Wallace Higgins concurred: Twelve to sixteen cars per hour fell far short of the “capacity” needed to transport peak-hour volumes implied by a ridership forecast of 50,000 per weekday, even with ridership divided between two corridors. But how to demonstrate this?

2) Supply-Side Analysis

The first step was definition of the following four parameters:

--Vehicles per Hour per Direction (VHD), a measure of “offered capacity.” This we defined as the maximum number of vehicles that a particular facility can operate in its existing configuration – with reference to existing vehicle fleet size, signal system, and site-specific constraints.

--Passengers Per Vehicle (P/V), a measure of “utilized capacity.” This we defined strictly as the maximum number of passengers likely to be observed on board, expressed as a one-hour, per-vehicle average at the maximum-load point.

--Average Weekday Ridership (AWR), the total number of passengers who board at all locations along the line, between the beginning and end of service on a typical business day. AWR does not include Saturday, Sunday or holiday ridership.

--The percentage of all weekday ridership that is carried during the busiest single hour, in the busier direction, past the maximum-load point along the line. This we dubbed “Peak Traffic Share,” or PTS. This variable does not have a “causal” relationship to AWR, but reflects the distribution of travel demand and service supply throughout the service day.

The mathematical relationship among the above may be expressed as follows:

a.) $\text{Passengers per hour} = (\text{VHD}) * (\text{P/V}).$

The peak-hour, peak-direction passenger volume is equal to the number of vehicles per hour, operated past the maximum-load point in the peak direction, multiplied by the average number of passengers aboard each vehicle.

b.) $\text{Passengers per hour} = (\text{AWR}) * (\text{PTS}).$

The peak-hour, peak-direction passenger volume is equal to the total number of passengers per weekday, multiplied by the percentage that travel during the busiest hour, in the busier direction, past the maximum-load point.

The “peak-hour, peak-direction passenger volume” is a “unique quantity” with reference to a specific corridor, location and time. Therefore, equations a.) and b.) may be combined by substitution as follows:

$$(\text{VHD}) * (\text{P/V}) = (\text{AWR}) * (\text{PTS}).$$

The “dependent” and “independent” labels were not used for the four variables because this was not thought necessary for a “verification” exercise. The value of the parameter of interest is that implied by the known or “given” values of the remaining three variables.

With tongues firmly implanted in cheek, Wallace Higgins and the author began referring to the above as “The Supply-Side Equation” (after “supply-side economics,” a legacy of the Reagan Administration). Thus, “supply-side analysis.” However, finding credible values for key parameters may require more time and effort than constructing one’s analytical framework.

3) PTS: The Thirteen Percent Solution

For the purpose of the verification exercise, values for two of the four parameters defined above could be determined in straightforward fashion: AWR from the weekday ridership forecast, and VHD from characteristics of the line in question (including vehicle fleet size, signal system and operating rules, and other site-specific constraints).

PTS, on the other hand, could vary over a wide range. If weekday ridership were distributed evenly over an 18-hour service day, the traffic carried during a single hour would be 5.6 percent of the total. If traffic volumes were perfectly balanced by direction, the theoretical minimum PTS would be about three percent. The absolute – albeit implausible – minimum, given a 24-hour service day and traffic perfectly balanced by time and direction, would be about two percent. The theoretical maximum PTS of 50 percent implies service limited to peak periods, and to the peak direction. If significant numbers of passengers travel in one direction only, returning by another mode, this “theoretical maximum” PTS might exceed 50 percent.

Knowing that the value of a key parameter is likely to fall between 0.03 and 0.50 – that is, between three and 50 percent – was of interest, but we needed greater precision.

Professor Jerry B. Schneider, Department of Civil Engineering, University of Washington, suggested, at spring 1990, use of 13 percent as a “benchmark” PTS value for radial CBD-to-suburb corridors in U.S. urbanized areas.

Professor Schneider’s suggestion proved remarkably robust. As outlined in the 1994 article, we were able to find a broad cross-section of data that provided firm support for a “minimum likely” PTS range of 10 – 15 percent. (More recent data suggests that PTS values for some U.S. rail corridors, certain LRT lines in particular, may fall below 10 percent.)

Note that the relationship between PTS and AWR, all else held constant, is inverse. In other words, with a given level of peak service and passenger tolerance for crowding, a smaller PTS implies a larger AWR. Therefore, the “minimum likely” PTS value is of interest for the verification exercise.

4) P/V: Where Did They All Get Off?

The next problem facing Wallace Higgins and the author was how to determine a range of likely values for peak vehicle occupancy (P/V).

Theoretical “capacity” figures were not of interest. Instead, we needed to know the maximum number of consumers who, on average, would choose to occupy an enclosed space such as an HRT or LRT vehicle. We recognized, in theory, that the average consumer might perceive a vehicle carrying a relatively small number of standees – or even a “full seated load” – as “overcrowded.” We did not suspect the degree to which this may be observed, and documented, in U.S. and Canadian cities.

Based on “then-current” planning assumptions, we assumed – “took for granted” is more accurate – that the “typical” P/V figure for articulated light rail vehicles (LRVs) would be 150.

But things did not turn out that way.

On the damp, chilly morning of December 6, 1991, we stood under the bridge at Skidmore Fountain station, Portland, counting inbound passengers aboard LRT trains. We observed that P/V was almost exactly 100 during the busiest hour of the a.m. peak – and that passenger loads were remarkably uniform during most of this “busiest hour.”

We concluded that Skidmore Fountain was not, as we had anticipated, near the actual “maximum-load point.” We took for granted that large numbers of inbound passengers had alighted somewhere “up the line” – that is, before trains crossed the Steel Bridge into downtown Portland. We simply did not consider the possibility that P/V could be as “low” as 100 per vehicle.

Not long thereafter, we obtained on-board ridership census data from the Tri-County Metropolitan Transportation District of Oregon (Tri-Met). Thanks to the kind cooperation of Tri-Met staff members, we were able to confirm that some passengers did alight at Eastside locations, notably Lloyd Center – but far fewer than 50 (average) per car.

What we saw, but did not believe, was in fact true: the P/V figure for Portland LRT fell roughly 30 percent below the figure we had anticipated.

We then set out to gather as much data as we could. These data established that, except on the busiest lines in Boston, Montréal, New York and Toronto, P/V figures as high as 150 pas-

sengers per vehicle do not occur on U.S. or Canadian rail transit facilities. (However, we did use 150 as the “upper boundary” of the P/V range for the JAPA article.)

We also established that peak hour passenger loads carried by busway/hov and freeway express bus services fell consistently below that carried by rail systems. The implication, to paraphrase a colleague’s comment, is that more “nominal capacity” must be provided with buses than with rail to transport a given peak-period volume. Wallace Higgins and the author do not pretend to understand *why* this occurs . . . but *that* it occurs is not subject to debate.

5) Early Ridership Forecasts: The Sacramento LRT System

As noted above, the maximum peak-period service supply at opening was limited to 12 VHD because of the initial vehicle fleet size (26 cars). Using a peak traffic share (PTS) of 13 percent (0.13; both corridors assumed to carry equal shares of total ridership), the smallest value supported by empirical data, the supply-side “test” of the early ridership forecast follows in straightforward fashion.

Referring to the supply-side equation above:

$$(VHD) * (P/V) = (AWR) * (PTS).$$

Substituting the three known parameter values, and treating the system as two radial corridors, each carrying 50 percent of weekday ridership:

$$12 * P/V = 25,000 * 13\%.$$

Solving for P/V:

$$P/V = (25,000 * 0.13) / 12$$

$$P/V = 271.$$

In other words, peak-hour volumes of the size implied by the early ridership forecast imply nearly 200 passengers, on average, aboard each vehicle during peak periods. A 20 percent PTS would imply more than 400 passengers jammed aboard each vehicle during the busiest hour. This absurdity and its implications appeared well known and widely recognized among U.S. transit professionals at 2005. However, a decade of stubborn resistance by most U.S. transport economists and many academics interested in transit issues continued unabated. This does not surprise, for reasons outlined below.

The largest value for P/V supported by empirical data is 115 (based on 5 passengers per meter of gross vehicle length, or P/M); available data support 100 as the “typical” value. The AWR correlated here may be calculated as follows:

$$12 * 100 = AWR * 13\%.$$

Solving for AWR (again treating the system as two radial corridors, each carrying 50 percent of weekday ridership):

$$AWR = 2 * [(12 * 100) / 0.13]$$

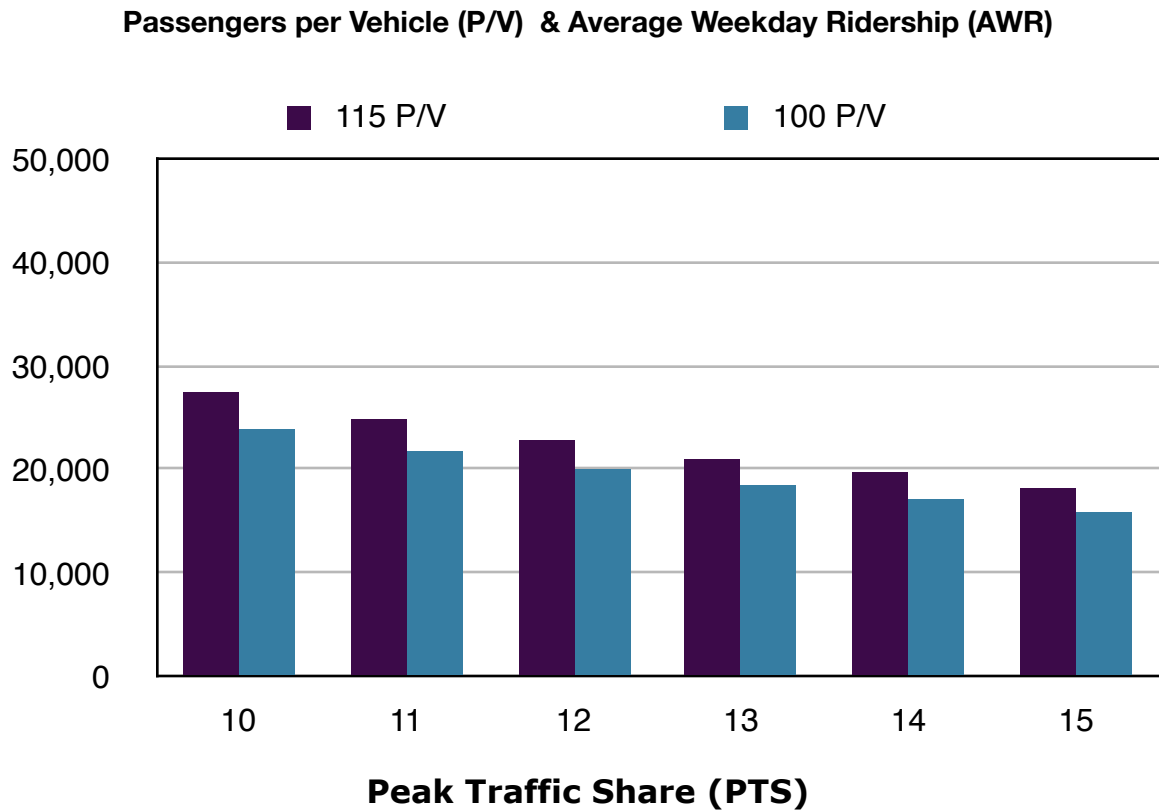
$$AWR = 18,500.$$

AWR levels implied by various combinations of PTS and P/V are illustrated in Figure 1 (below). The “supply-side” estimate above is 10 percent less than the “Preliminary Engineering / Final Environmental Impact Statement” (PE/FEIS) forecast of 20,500 per weekday. However, with reference to the maximum peak-period service level at opening, no likely values of PTS and P/V were correlated with an AWR as great as 50,000 per weekday. The “maximum likely” AWR in the “as built” configuration was less than half of the “year 2000 AA forecast.”

Significant growth in AWR was not likely absent one or more of the following:

- Provision of additional service supply during periods of peak travel demand, (thereby increasing VHD).
- Spreading periods of peak demand over longer intervals through travel demand management (TDM) strategies, permitting existing services to accommodate a larger share of potential consumption (thereby reducing PTS).
- Increased off-peak or reverse-peak traffic as the result of long-term land-use changes (thereby reducing PTS).
- Willingness of consumers to tolerate higher levels of peak-period crowding (thereby increasing P/V) because of various “demand” factors (e.g. gasoline prices, downtown parking supply and cost).

Figure 1: Peak Traffic Share (PTS),



In Sacramento, the most significant factors leading to doubling of AWR during the first years of operation were 1.) improved coordination between rail and bus services, and 2.) procurement of additional rail vehicles, permitting increased peak-period service supply.

6) Consumption or Productivity: Which to Maximize?

Often ignored in the debate over ridership forecasts is the fact that Sacramento planners decided the “theoretical maximum” ridership of 50,000 per weekday was not the “best” public-policy choice.

The transit system outlined at the “Alternatives Analysis / Draft Environmental Impact Statement” (AA/DEIS) stage was found, during subsequent analysis, to have low productivity in terms of passengers (boardings) per revenue service hour. Existing transit service levels would have to be doubled in order to carry the “systemwide” forecast of 112,000 “linked trips” (“revenue passengers”) per weekday. A service increase of this magnitude would require a fleet of 39

railcars and 400-500 buses. This was judged infeasible on cost grounds. Planners worked to maximize productivity rather than ridership during the “Preliminary Engineering / Final Environmental Impact Statement” stage. The revised system, although forecast to carry significantly lower ridership (20,500 per weekday at opening), required lower expenditures for infrastructure, vehicles and operations and achieved greater productivity (Schumann 1990).

Critics such as Lave (1991) typically use phrases such as “spin control” and “bait and switch” to describe revisions of the type outlined above. Lave, however, fails to explain why reconciliation between demand and supply parameters should not be performed.

Lave (1991) also fails to explain the logic of providing service levels sufficient to accommodate all “potential” consumption – that is, the totality of demand. Such a transit facility would be very costly to build, operate and maintain. It would require full separation, multiple tracks, large stations, long platforms and a large vehicle fleet. A great deal of “capacity” would not be used during most of the day. The “peaking effect” (or “peak-to-base ratio”) would be very high, and this would exert a strong upward influence on operating costs.

7) Sacramento Light Rail Ridership: Forecast & Actual

Sacramento’s initial light rail service, from downtown to Watt/I-80, opened on March 12, 1987. The starter system was completed on September 5 with the opening of revenue service to Butterfield (Beach 1992).

The AA/DEIS forecast of 50,000 passengers per weekday was based on a 20-year horizon (“year 2000”) and was not appropriate for comparison with results observed during the initial operating period.

The PE/FEIS estimate for the initial ridership was 20,500 per weekday. At opening, without “timed transfer” coordination between bus and rail services, and without the large increase in bus service outlined at the AA/DEIS stage, average weekday ridership was 13,200. In 1989, led by General Manager Thomas G. Matoff, SRTD implemented a major restructuring of its bus network, fulfilling the “coordinated transit” element of the project plan. SRTD also added ten additional railcars that same year, providing increased peak-period passenger capacity. AWR reached the PE/FEIS forecast level within one year, and grew to more than 26,000 by 2000. This occurred without the high gasoline prices, high downtown parking costs and limited supply, and doubling of the bus fleet anticipated at the AA/DEIS stage (Schumann 2005).

SRTD opened a 2.3-mile (3.7-km) extension of the Folsom Line, from Butterfield to Mather Field Road, on September 6, 1998. AWR grew subsequently to 30,000. The initial stage of the South Line (6.3 mi, 10.2 km) was opened to Meadowview Road on September 26, 2003, followed by a Folsom Line extension to Sunrise Boulevard (2.8 mi, 4.5 km) on June 11, 2004. RT Metro AWR was reported at 44,000 at April 2005.

8) Conclusions & Discussion

Exercises similar to that above may be performed for other U.S. rail projects opened from the early 1980s. In the majority of cases, results suggest that early planning forecasts were prepared with little reference to service supply parameters – or no reference at all. Comparisons between crude “forecast” and “actual” ridership would therefore relate forecast travel demand to actual service consumption – a classic “apples and oranges” paradox.

The conclusion likely to stir the greatest amount of cognitive dissonance: Disparity between forecast and observed levels of consumption (ridership) provide no grounds for conclusion that the forecasts in question were “incorrect.” If the requisite service levels were not provided, then the forecasts were not tested.

A “ridership” forecast prepared with inadequate reference to service supply factors does not necessarily reflect “erroneous” demand forecasting. Travel demand modeling does not account for “real-world” constraints imposed by service-supply factors. The classic four-stage demand modeling procedure (see, for example, Meyer and Miller 1984) determines the transit “share” of overall travel based on time and cost factors, but does not consider the “limit” (or “ceiling”) imposed by service-supply factors. Various sources on travel-demand forecasting techniques provide little information on supply analysis. This is not surprising, for demand and supply analysis are separate procedures. In addition, reconciliation between supply and demand factors was repetitive, tedious – and costly. Analysis of this precision might not have been considered “appropriate” for “early planning” on cost grounds.

On the *relevance* of disparities between “forecast” and “actual” ridership (whether arising from forecaster bias, technical issues or other factors), Pickrell (1989) acknowledges the difficulty in determining whether different (e.g. more accurate) estimates would have led to different outcomes. Brinkman (2003) states explicitly that forecast accuracy is an issue only to the extent that decision makers use such forecasts as decision criteria. Belobaba (1982) states that non-technical and political factors have as least as much influence as funding issues in determining the form of transit projects. He states that technical considerations are often used to support

design decisions that were induced by non-technical factors. Johnston et al. (1991) criticize the choice of light rail in Sacramento, but acknowledge Belobaba's points as follows:

While we do not advocate pork-barreling, we believe that the choice of LRT, to the extent that it reflected legitimate local concerns, was valid.

Pickrell (1989), Brinkman (2003), Belobaba (1982) and Johnston et al. (1991) avoid the trap that so firmly ensnares Flyvbjerg et al. (2002, 2005). Flyvbjerg and his collaborators imply that benefit/cost analysis is (or should be) the primary or exclusive criterion used by "decision makers" – but cannot bring themselves to state this explicitly. Apparently, Flyvbjerg et al. are not prepared to challenge the large body of literature that documents exactly the opposite. Their failure to address the relative weight of "non-technical and political factors" compared to benefit/cost analysis is a glaring omission but does not surprise.

9) A Postscript

The past ten years have seen significant advances in biology, chemistry, medicine, physics, engineering and applied technology, among other fields. Transportation planning has also advanced; today's professionals have access to more and better data, and greater analytical capabilities because of the proliferation of desktop computing and task-specific software packages. Much has been learned about ridership forecasting over the past decade, reducing the probability that the errors of the past will recur.

To give just one example: it is now clear that U.S. and Canadian consumers will not accept the loading standards used for many planning studies during the 1970s and 1980s. In Portland, operator staff members have concluded that transit consumers will not accept LRT vehicle occupancies greater than 135 P/V (4.9 P/M), except for special events. Prior to construction, planners estimated the capacity of each 90-foot vehicle at 166 passengers (6.1 P/M) based on 76 seated passengers and four standees per square meter. This loading standard was based on (West) German experience (Schumann 2000).

Quite in contrast are the efforts of certain U.S. transport economists and many academics interested in public transit to "prove" that the primary causal factor accounting for ridership "shortfalls" is forecaster "bias." Such bias occurs without question but its impact is less certain. The author believes that the "technical" issues outlined above might exert relatively more influence.

The theory that “bias” is the most significant factor explaining ridership “shortfalls” (and cost “overruns”) has become a virtual ideology. Resistance to considering such technical issues among certain economists and academics is therefore not surprising. Clear and cogent proof that Sacramento’s LRT system “as built” could not carry 50,000 passengers per weekday – and that the “maximum likely” ridership was less than half this figure – might prove difficult to explain away in terms of “bias.” Similar proof for other rail projects opened from the 1980s would also jeopardize dogma of “forecaster bias.”

The “bias theory” will not soon fade; the sheer magnitude of the effort expended by prominent academics over more than three decades to prove “bias” insures this. Flyvbjerg et al. (2005) are merely the most recent authors to ignore technical issues that might topple the ideological structure like the metaphorical “house of cards.” However, the time will come when “bias theory” proponents will no longer enjoy this luxury; they will eventually need to address technical issues in order to retain credibility. Facts and reason will ultimately prevail.

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