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Towards a Level-of-Service Measure for Mass Transit

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2nd Prize—Best Graduate Student Paper

I. INTRODUCTION

Public transit systems may be properly evaluated for policy purposes in a number of ways. Among the more common tools for evaluation are measures of a transit system's performance from a fiscal point of view, such as passengers or revenues per operating mile, or farebox recovery ratios. Less developed are evaluation techniques that adopt the perspective of the transit passenger and attempt to measure the quality of the service received and facilitate service comparison over time or between transit systems. The concept may be referred to as an extension of "level of service" (LOS) measures commonly used in street and highway planning to the realm of public transit.¹ This paper will examine some of the attempts to develop transit LOS measures, suggest criteria for the evaluation of such measures particularly as they are influenced by land use patterns, and offer proposals towards the development of a standardized LOS measure for transit operations.

II. PURPOSES OF A TRANSIT LOS

The need for a transit LOS measure stems from transit's shift over the past few decades from private to public ownership. When profit was the motive for running streetcars, profit would also be the criterion by which changes in service were evaluated.² Current transit decisions are less singular and require multifaceted evaluation criteria. When considered within its specific land use context (that is, avoiding comparisons between systems operating under widely differing density conditions) a transit LOS may serve as such an evaluation measure. Botzow³ proposes LOS for the purposes of rating existing modes and specifying service goals to be sought. Allen and DiCesare⁴ extend the goals to include policy formulation and monitoring, enabling the linkage of subsidy to performance, facilitating transit agency management and generating public information and involvement. Flyvbjerg⁵ emphasizes the public involvement aspect, seeing transit LOS primarily as a tool to elicit effective citizen participation in transit planning.

Flyvbjerg also raises the question of the appropriateness of a performance measure (typically a tool of a technocratic planning style) to a more open system of planning of which citizen participation is an integral part. He shows that there is no conflict between the two as long as the measure itself is inexpensively produced, directed at evaluating specific problems (and not just macro or region-wide issues), and most importantly, understandable. To Flyvbjerg a measure is understandable to the lay person if it is scaled in real terms; for example travel time in his scheme

is measured in minutes and is not combined with other service elements to generate an arbitrary "A" through "F" measure.

This approach gives rise to several difficulties in a tradeoff between the values "understandable" and "usable." Specifically, unless a LOS measure develops a weighting system to render service elements commensurable, the lay person will be unable to use it to decide whether a service change that, say, increased frequency while decreasing speed but holding reliability constant, leaves the community better or worse off than before. Moreover, without such a measure, a statement such as "our city gets 'X' level service while their city gets 'Y'" would be impossible, and the value of the measure for comparison purposes would be sharply cut. In addition, certain service variables (notably comfort) may be readily measurable but even the untransformed units of measurement (acceleration per second per second, cubic meters of ventilated air per second) are utterly meaningless to the lay person. For these reasons this paper will focus on LOS determination efforts that attempt to achieve a single measure reflecting transit's many aspects. They may thus sacrifice a measure comprehensibility but are more than compensated by their increase in usefulness.

III. DEFINITION AND MEASUREMENT OF SERVICE VARIABLES

LOS measures such as these will contain three chief elements: a definition of relevant service variables, an approach to their measurement, and a scheme to weight the outcomes to reach a single measure of service level.⁶ Mundy⁷ criticizes LOS measures that take this form on the grounds that they focus on traditional transit to the exclusion of the broad spectrum of alternatives between transit and the private automobile. But comparing service levels between a range of modes is a daunting task, in part due to the fact that certain service attributes (such as headways between transit vehicles) are mode-specific. For this reason this paper will focus on measures of the type described above.

In keeping with the goals of LOS measurement, the following criteria are proposed to guide the acceptance or rejection of proposed LOS measures:

The measures should be user-oriented and service-oriented. Thus the measurements themselves will avoid judgments regarding what the transit operator may reasonably be expected to provide, focusing instead on what the patron actually receives. The fare the passenger pays must not be included in a level of service measure. Indeed LOS may fuel debates for fare changes based on better or poorer service; including the fare itself within the measure would confuse the issue.

The number of variables must be small enough for the measure to be usable. Thus the approach of Allen and DiCesare⁸ who specified at least twenty seven variables (including such marginal items as average curb-to-vehicle step height) to be included in a LOS measure is to be avoided.

The number of variables must be great enough to reflect different significant attributes of public transit. Polus and Shefer⁹ based their measure on speed alone, Bakker on seat availability,¹⁰ while Flyvbjerg¹¹ based his on travel time and cost. These extremely limited approaches, though enjoying the advantage of simplicity, sacrifice too much information about other trip aspects to be useful LOS measures.

No significant aspect of the transit trip should be a priori excluded from the analysis. Alter¹² arbitrarily excludes "hygiene" variables from his LOS measure, asserting that a lack of cleanliness, comfort or safety can discourage a rider but their presence can never motivate a potential rider. The fallacy of this statement is readily apparent; the rider who was previously repelled by poor cleanliness, comfort or safety may well be wooed back by improvements in these areas. Moreover, surveys have shown safety and comfort to be important determinants of mode choice.¹³

The above criteria suggest the definition of a handful of service variables that can describe the major aspects of the transit trip. Following is a description of the major areas to be considered.

A. In Vehicle Travel Time

Botzow¹⁴ measures trip time in miles per hour, specifying goals together with his measures: 35 miles per hour in line haul operations, 6 to 15 miles per hour in CBD areas, based on a maximum door-to-door travel time of one hour. Alter¹⁵ avoids the complexity of such arbitrary definitions by basing his travel time variable on the ratio between transit trip time and automobile trip time. Subsequent authors¹⁶ have followed Alter's approach, with the exception of Flyvbjerg¹⁷ who uses minutes spent in travel as the relevant measure of travel time.

Flyvbjerg's approach also combines in vehicle trip time with out of vehicle trip time, thus ignoring the significantly higher psychological cost of the latter¹⁸. The approach makes two important contributions, however. First, Flyvbjerg bases his analysis on a survey of the population served that uncovers the desired trips and trip times, matching them with timetables to derive actual trip times. This approach enables him to measure another variable he calls "hidden waiting time," being the difference between the time a person actually arrives at a destination and the time he or she needed to arrive. Thus a worker who has to be on the job at eight in the morning but is forced to arrive at 7:45 due to bus scheduling is enduring fifteen minutes of "hidden waiting time."

A combination of the approaches suggested by Alter and Flyvbjerg may prove particularly useful. In recognition of the fact that in the American context the chief competitor of public transit is the private automobile, Alter's relative speed measure should be used. But in order to ensure that the relative speed is calculated for a typical trip rather than an ideal one (and to measure service for poten-

tial users as well as actual), Flyvbjerg's survey approach may be employed.

The survey approach will also generate a "hidden waiting time" variable, though this information should not be automatically lumped into travel time; it is reasonable to expect it to have a different cost to the passenger from travel time itself. On the other hand, the "hidden waiting time" effect is at least partly captured by the frequency of service variable described below; empirical analysis would likely show the two variables to be describing the same kinds of costs to the passenger. I am proceeding on the assumption that service frequency captures much of "hidden waiting time" but more adequately describes the disutility of fixed schedules to the customer.

B. Service Frequency

The frequency of service is generally accepted as an important determinant of transit LOS, and attempts to measure this service characteristic within an LOS context have taken two approaches. The first approach (which was adopted by Botzow¹⁹) utilizes the common approach of adding one-half the average headway to the travel time. This technique leads to several difficulties, however. First, as Botzow himself points out, when headways rise to much above ten minutes passengers begin to use timetables and the implicit presumption that the average wait equals half the average headway no longer holds.²⁰ (For this reason Botzow proposes adding half-headway times to travel time to a maximum of five minutes, thus placing a system with thirty minute headways on the same level as one with ten minutes separating its vehicles.)

The second reason the "half average headway" method is problematic is the implicit presumption that waiting time is viewed by the passenger equally as "costly" as in vehicle travel time, a presumption disproven by numerous studies.²¹ An approach separating the two and allowing them to carry differing weights (as discussed in Section IV below) will better reflect their impact on the service levels passengers perceive.

Such an approach is advocated by Alter²² who uses average headways directly as a measure of service. Though this may be the best measure it should not be applied blindly; for example a transit operator running very frequent commuter service during peak hours but little service the rest of the day would not be evaluated on an all day basis. Rather, two LOS measures would need to be computed for such an operator: one for commute hours, the other for the off-peak.

Another potential pitfall of this measure would be an assumption that the relationship between frequency and passenger-perceived service is linear. In fact it is markedly nonlinear over the relevant range; a change from 5 to 20 minute headways is significantly worse than a change from 30 to 45 minute headways, from the passengers' point of view.

C. Accessibility and Out of Vehicle Travel Time (OVTT)

The range of activities a passenger needs to engage in just to ride a transit vehicle is great. Horo-

witz²³ writes of bus travel: "In contrast to competing modes, a relatively small percentage of the effort expended in bus transit travel actually results in physical progress toward a destination. Transit users spend substantial amounts of time planning their trips, coping with unfamiliar areas, dealing with crowds, contending with the weather, walking, waiting, transferring, or otherwise satisfying the basic constraints of the bus mode." This range of OVTT activities and the varying costs passengers attach to each of them makes accessibility a particularly difficult variable to measure in an LOS context. The difficulty stems not so much from an inability to define or measure the range of these activities as a need to keep LOS measures simple and inexpensive to produce.

An approach adopted by Allen and DiCesare²⁴ calculates that the ratio of route-kilometers to catchment area-kilometers to determine the degree of coverage the transit operator is offering. The difficulty with this approach is in its inherent assumptions regarding land use patterns throughout the catchment area. If both population and employment are relatively concentrated along certain corridors, the region may be quite well served by a skeletal network. (Such may be the case in cities with radial street and highway patterns, for example). If the inherent assumption of uniform distribution of population and employment throughout the catchment area is a rough approximation of reality, this measure may be appropriate as long as it is used in conjunction with a measure of route directness (such a number of transfers) and service frequency.

Perhaps more all-purpose measures are suggested by Bullard²⁵, who used simple OVTT or Alter²⁶, who used distance to and from the trip ends²⁷. An advantage of OVTT over distance as a measure of accessibility is that OVTT, unlike distance, can measure time spent in transferring²⁸. On the other hand, OVTT can underestimate the difficulties of access to transit since it values identically a walking trip and a driving trip of equal time to a bus stop. Hence, if OVTT is selected as the measure, an auto access dummy variable should be added, while if distance to the trip ends is used to indicate accessibility, time spent in transferring will have to be measured separately.

In either case, the number of transfers required should be counted separately to allow for the likelihood that the very fact of transferring imposes a psychological cost on a passenger over and above the time spent in transferring.

D. Service Reliability

Reliability can be roughly defined as the passenger's degree of certainty of arriving according to schedule. Hence Botzow's variable of average minutes of delay per trip²⁹ is probably inadequate as it says nothing of the likelihood of experiencing a significant delay. Regular delays of 5 to 10 minutes are likely to be perceived quite differently from the occasional long delay due to traffic jams or equipment failure.

Alter³⁰ measures reliability so as to capture this aspect; he proposes to compute the percentage of vehicles that run between one minute early and three minutes late.³¹ Reliability of this sort must be measured relative to service frequency; the effects of

lateness on a 12 vehicle per hour line are much less severe than on a 1 vehicle per hour line.

E. Comfort and Security

Comfort and security, dismissed by Alter as "hygiene" factors, may in many cases determine mode choice. But they are particularly difficult aspects to measure, since they are the most subjectively determined of all LOS elements.

For example, security may be measured on the basis of transit crimes or accidents per million vehicle kilometers³² (security from crime is likely to be the dominant concern). But a number of intangible or uncontrollable factors (such as the systems safety "image" or the fear of crime while travelling to and from the system) may shape people's preferences more than actual crimes.

The measurement of comfort poses difficulties of a different nature. First, comfort in transit is composed of a large number of elements, including seat availability and quality, crowdedness, ventilation, temperature, cleanliness, odors, and for standees, acceleration, jerk and sway. Secondly, these elements are perceived differently by different individuals, and perhaps most importantly, they are perceived as a bundle; most passengers do not consciously consider each of these elements, but evaluate the entire trip as "comfortable" or "uncomfortable." Perhaps the most comprehensive approach to the development of a "comfort" variable would be an experiment in which passengers were asked to rank various transit rides on a "comfortable" "uncomfortable" scale; the results could then be regressed on the comfort elements mentioned above.

If this comprehensiveness proves unfeasible, an acceptable simplification may be to adopt a single variable (seat availability would be a likely candidate) as a proxy for all others. The strength this admittedly simplified approach is that the availability of a seat enables a passenger to withstand many other affronts to his or her comfort.

IV. WEIGHTING OF SERVICE VARIABLES

As discussed above, the combination of the diverse service elements comprising the transit trip experience in a single LOS measure demands a scheme that would assign varying weights to the different elements. Most authors proposing multivariate LOS measures have in fact used weighting systems, but the weights used, even if reflective of the authors' knowledge of transportation demand characteristics, were remarkable arbitrary.

For example, Botzow³³ based his weights on a survey of Washington D.C. transit riders, calculating them from the frequency of criticism reported regarding each service element. The following weights are thus produced: Speed, 30 points; density (i.e., crowding) 25 points; temperature, 15 points; delay and acceleration (i.e., jerk), 10 points each; and ventilation and noise, 5 points each.

The weaknesses of this approach are several. First, it is based on what people say they care about and not their observed behavior. Thus the results are most likely skewed toward the most noticeable shortcomings of the D.C. system. Furthermore, the sur-

vey questioned current system riders only. By neglecting potential riders the results were probably biased toward certain transit characteristics. The precise degree and direction of bias cannot be determined without further empirical analysis but 60 points out of 100 devoted to comfort related variables (density, acceleration, temperature, ventilation and noise) is probably an overstatement of comfort's relative importance.

In a similar fashion, Bullard³⁴ developing a weighting system based on ridership surveys, while Alter³⁵ created a weighting system he identified as "arbitrary." "Ridership," he writes "is a response to an offered LOS. As such it (ridership) is an important performance indicator but in no way directly measures LOS³⁶." The problem with this approach is that it gives rise to the arbitrary determinations that Alter made, which in turn carry the danger of identifying "improvements" in LOS that drive riders away and "deterioration" that attracts them. Logically a change in the bundle of attributes that constitute LOS is an improvement if and only if it has the potential to attract a larger ridership.

Such a view would lead the LOS measure developer to models of modal split to examine variable coefficients as potential bases for service element weights. Existing modal split models might also provide some answers on the validity of the more arbitrary LOS weights. Unfortunately, a direct comparison of existing LOS measures with existing multinomial modal split measures is hampered in two significant ways. First, crucial LOS elements, such

as comfort, are missing from most modal split models. Secondly, variables are frequently measured differently in modal split models and LOS measures. For example, travel time tends to be measured in absolute terms in modal split models but as a ratio (transit to auto) in LOS measures, thus rendering the coefficients incomparable.

But limited comparisons are possible through hypothetical scenario testing. Using the comparable elements of a single logit modal split model and an single set of LOS weights one can compare the assessment each scheme would give to a change in transit service. The LOS weights and the logit model coefficients used for this comparison are presented in Table 1. It should be noted that both the logit model and the LOS system contained a number of other variables; only those that were directly comparable were utilized.

Two scenarios are presented in Table 2; using a reference automobile trip of 20 minutes IVTT and 3 minutes OVT, two hypothetical bus trips are compared under Bullard's LOS weights and Train's logit coefficients. The results demonstrate the inconsistency of the LOS measure with the modal split model; the second bus trip will attract a smaller mode share than the first, yet its LOS "increased" from something under a "C" to a flat "C." The "improvement" in service levels drove away passengers!

Valid LOS measures thus must justify their weighting schemes. The methodology for doing so is well known; the maximum likelihood estimation used in multinomial logit modal split analysis is

TABLE 1
LOS Weights and Logit Modal Split Model Coefficients

Service Element	Logit Coefficients ³⁷	LOS Weights ³⁸
IVTT	-.0201	10
Walk Time	-.0464	10
Number of Transfers	-.0656	10

TABLE 2
Comparison of Hypothetical Transit Trips Under LOS Weights and Logit Model Coefficients

Trip #1: Element	Bus	Auto	Utility (Bus)	Utility (Auto)	LOS (Bus)
IVTT	30	20	-0.603	-0.402	D
Walk Time	3	3	-0.139	-0.139	B
Transfers	2	0	-0.131	0	D
Total			-0.873	-0.541	
Bus' market share under this scenario: 41.8%					
Overall Level of Service Ranking: C-					
Trip #2: Element	Bus	Auto	Utility (Bus)	Utility (Auto)	LOS (Bus)
IVTT	35	20	-0.703	-0.402	E
Walk Time	6	3	-0.278	-0.139	C
Transfers	0	0	0	0	A
Total			-0.981	-0.541	
Bus' market share under this scenario: 39.2%					
Overall Level of Service Ranking: C					

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entirely appropriate for generating LOS weights as well. Such studies would have to be tailored to LOS purposes in their variable specification. But the relative stability of the coefficients of modal split models over time and across geographic regions offers hope for similar stability in LOS weights.

V. LAND USE PATTERNS AS A DETERMINANT OF TRANSIT LOS

It is easy to show how land use patterns are a direct determinant of LOS; higher density, for example, will almost always allow a greater frequency of service. Traffic congestion will constrain bus speed. Even the layout of the street network determines service characteristics; the grid system enables quite direct travel to all points³⁹, while a radial system may allow for more frequent service along the "spokes."

But more important to the design of LOS measures is the question of whether and how LOS should be measured differently according to land use conditions. For example, if fifteen minute headways are considered level "D" for urban areas, might they be considered level of service "A" or "B" for suburban districts? Several authors⁴⁰ have proposed such more lenient standards for less dense areas. However no author has considered explicitly the justifications for varying the measure to suit the area.

Such justification needs to be carefully examined. If LOS is intended to be a unit of measure, it should be independent of any standard that is to be advocated or imposed. Arbitrarily varying the measure to suit local conditions is akin to defining 70 degrees fahrenheit to be "the desired ambient temperature" whether that temperature is measured in an office building, an old age home, or a food storage locker.

Two possible justifications come to mind when one is considering varying LOS according to land use conditions. Two of them have no proper bearing on LOS measurement.

A. Transit operators cannot reasonably be expected to provide the same level of service in suburban areas as in urban. While this statement is true it is irrelevant to LOS measurement. As opposed to measures of financial performance, LOS is intended to be user-oriented; that which the operator may be expected to provide bears no relationship with what the user in fact receives.

B. Residents of suburban communities want less transit than those of urban areas. Again the statement is probably true, but need have no bearing on LOS measurement. One of the chief purposes of an LOS measure is the stimulation of public involvement in transit planning, and such involvement almost always entails differences of opinion between citizens. There will be ardent transit advocates even in the suburbs; to artificially inflate the LOS they are reported to receive is to deprive them of an important tool for influencing debate.

C. LOS is perceived differently under varying conditions. This is the sole proper justification for varying LOS measurement according to local conditions. It does not justify adjusting the vehicle headway categories in areas of sparser development⁴¹, but it may have influence in other areas.

For example, as discussed above, the importance of on-time reliability grows with the headways between vehicles; a once-an-hour bus must be on time, while delays on a very frequently served line would be barely noticed. Thus it would be entirely legitimate to grant a "D" ranking to a suburban half hourly service with an 85 percent on-time record, but an "A" ranking to an 8 minute headway urban service with the same record⁴².

Another example of LOS perceptions varying according to local conditions might be in the area of comfort. On a very short CBD ride, for example, the lack of a seat might be of little importance (many people would find it barely worthwhile to take off their coat and set down their parcels anyway); such a ride might be ranked "B" in comfort terms. But in a 45 minute line haul from the suburbs, the lack of a seat would certainly be ranked "F" in its discomfort producing potential.

In a similar fashion, comfort variables such as acceleration, deceleration, jerk and sway may be measured relative to seat availability, as they are most important to standees. Systems where virtually all passengers have a seat (as is typical for suburban systems) may be permitted a fairly rough ride and still be granted a high comfort grade. Systems in which standing is common will have to ride more gently to be given a high ranking.

V. CONCLUSION

For a transit level of service measure to fulfil its potential in transit evaluation, planning and citizen participation, the concept would need to become widely standardized and accepted. Despite the efforts of a number of authors, thus far nothing approaching a standardized measure has been developed. This is largely attributable to the difficulty of generating general acceptance of a measure that includes so many subjectives. If there is a way to overcome this obstacle it is through more careful specification of LOS models and greater justification of the systems developed to rate the relative importance of each element of the LOS measure.

ENDNOTES

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2. Bullard, Diane L. and Christiansen, Dennis L. "Level-of-Service Concept Applied to Public Transportation." *Texas Transportation Institute, The Texas A&M University System, College Station* [1981]. *Technical Report 1067-1F, Study 2-10-81-1067*, p. 1.
3. *Ibid.*, p. 73.
4. Allen, William G., and DiCesare, Frank D. "Transit Service Evaluation: Preliminary Identification of Variables Characterizing Level of Service." *Transportation Research Record* 606 [1976], p. 43.
5. Flyvbjerg, Bent, et al. "Evaluation of Public Transport: Method for Application in Open

- Planning." *Transportation* 13 [1986], pp. 23-52.
6. The LOS measure may be computed for the transit system as a whole, a geographical or temporal subunit, or a single line.
 7. Mundy, Ray A. "Mass Transit Guidelines Versus a Consumer Orientation in Public Transit Systems." *Transportation Research Record* 625 [1977], p. 34.
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 9. Polus, Abishai, and Shefer, Daniel. "Evaluation of a Public Transportation Level of Service Concept." *Journal of Advanced Transportation* 18:2 [1984], pp. 135-144.
 10. Bakker, J. J. "Transit Operating Strategies and Level of Service." *Transportation Research Record* 606 [1976], p. 5.
 11. Flyvbjerg, op. cit.
 12. Alter, Colin H. "Evaluation of Public Transit Services: The Level of Service Concept." *Transportation Research Record* 606 [1976] p. 40.
 13. Mundy, op. cit., p. 35.
 14. Botzow, op. cit., p. 74.
 15. Alter, op. cit., p. 38.
 16. For example, Bullard and Christiansen, op. cit.
 17. Flyvbjerg, op. cit. pp. 27-31.
 18. Horowitz, Alan J. "Subjective Time in Bus Transit Travel." *Transportation* 10 [1981] 149-164.
 19. Botzow, op. cit., p. 75.
 20. On the other hand, half average headway may be a reasonable proxy for waiting time plus "hidden waiting time."
 21. For example, Bakker, op. cit., p. 2.
 22. Alter, op. cit., pp. 38-39.
 23. Horowitz, op. cit., p. 149.
 24. Allen and DiCesare, op. cit., p. 43.
 25. Bullard, op. cit., p. 2.
 26. Alter, op. cit., p. 38.
 27. Similarly to in vehicle travel time, these measures are most appropriately based on survey data.
 28. Though time spent walking to a transit vehicle will have a different "cost" from that spent transferring from vehicle to vehicle, the cost of each will be higher than that of in-vehicle travel time; I am combining the two for simplicity.
 29. Botzow, op. cit., p. 75.
 30. Alter, op. cit., p. 38.
 31. Whether a vehicle leaving one minute early is to be considered "reliable" may be debated; Bullard (op. cit., p. 21) uses "zero minutes early" as her standard.
 32. Allen and DiCesare, op. cit., p. 43.
 33. Botzow, op. cit., p. 82.
 34. Bullard, op. cit., p. 29.
 35. Alter, op. cit., p. 39.
 36. Ibid.
 37. Train, Kenneth. "Work Trip Mode Split Models: An Empirical Exploration of Estimate Sensitivity." Working Paper #7602, Urban Travel Demand Forecasting Project, Institute of Transportation Studies, University of California, Berkeley, 1976, p. 14.
 38. Bullard, op. cit., p. 30.
 39. Bakker, op. cit., p. 2.
 40. For example, Alter, op. cit., and Dawson, W. R. "An Approach to Urban Transit Service Standards in a Regional Context for Small and Medium-Sized Communities." *Transportation Forum* Vol. 1-3 [1984], pp. 5-12.
 41. If a single scale of headway categories is to be used to describe service under all land use conditions, the scale must be finer grained than the six-point A through F scale. It would be inadequate to lump all service with headways above 30 minutes into the "F" category.
 42. This approach was used by Alter, op. cit., p. 39.