ANALYSIS OF THE TRADE-OFF BETWEEN LEVEL OF LAND ACCESS AND QUALITY OF TRAFFIC SERVICE ALONG URBAN ARTERIALS

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The objectives of this research were to analyze the rate at which units of traffic service are substituted for increments of land access and to evaluate alternative measures of level of land access. Several four-lane undivided arterials in Madison, Wisconsin, were selected for study. Each arterial was subdivided into sections approximately 0.2 mile in length. Roadway and land use characteristics were recorded for each section, and the average unit travel time within each section was measured for each direction of travel during five different time periods. Multiple linear regression analysis was then used to express unit travel time as a function of level of land access and other influencing variables. The analysis revealed that, as the number of daily trip ends per mile or the amount of commercial floor area per mile increases, unit travel time also increases, the amount of change being dependent on the time of day. Although quantifying level of land access by a trip generation rate is intuitively more desirable, the commercial floor area measure is more easily determined. The results of the research illustrate the importance of the control of roadside development as a means of preserving the quality of traffic service provided by urban arterials.

•PROVISION of land access and movement of traffic are the two primary functions of an urban street system. Because it is impossible for a given roadway to concurrently perform both functions efficiently, streets and highways are classified and designed based on the proportion of land access and traffic movement to be provided. In the case of an arterial roadway, the major purpose is to provide for the safe and efficient movement of relatively high volumes of traffic. Its secondary purpose is to provide relatively low levels of direct access to abutting land uses.

Because of the general absence of land access controls along urban street systems, the performance of newly constructed or improved arterials frequently deteriorates because of increases in the level of roadside development. This not only generates new sources of traffic demand that must use the facility but also reduces the original traffic service capability of the roadway. This process can thus lead to the early functional obsolescence of the highway facility.

Potentially, one of the most effective methods of preserving the utility of urban street systems is by means of a set of highway access and land use controls (9, 10, 11). These controls would define the specific levels of land access to be allowed along any given roadway. Ideally, the measure of land access would consider the number, type, and traffic generating characteristics of abutting land uses having direct highway access.

One of the major obstacles to this type of land use control is the lack of knowledge concerning the precise interrelation between level of land access and quality of traffic service. Research to date has shown that commercial roadside development does affect travel speeds and delay to through traffic. Horn et al. (7) found that, for a given traffic volume, speeds along developed sections of two-lane roadway in North Carolina were lower than those along underdeveloped test sections. In a subsequent study, Cribbins et al. (3) found that the log of travel time per mile along divided highways was inversely related to the number of access points per mile raised to the second power. The access-point parameter was designed to evaluate the number of conflicts introduced into the traffic stream. The number of access points for a particular abutting land use was simply an estimate of the average daily traffic generated at that location. In 1967, Treadway and Oppenlander (12) reported on a research study of speeds and delays along a two-lane urban bypass facility in Lafayette, Indiana. Their analysis revealed that the number of intersecting streets per mile and the number of commercial establishments per mile were both inversely related to mean travel speed.

Thus, although previous research has indicated that level of land access is inversely related to the quality of traffic service provided by a roadway, there is incomplete knowledge regarding the rate at which units of traffic service are substituted for increments of land access or the most suitable measure of level of land access. The research described herein represents an attempt to begin to solve these two problems.

PROCEDURE

The primary hypothesis to be tested was that an inverse relation exists between the traffic generated by roadside development and the quality of service to through traffic. As a corollary, it was also hypothesized that quality of traffic service is inversely related to the type and intensity of land use found along the highway. The approach of this study was to statistically analyze these interrelations using data to be collected for sections of four-lane undivided arterials in the Madison, Wisconsin, urban area.

Study Variables

Those variables that were selected to represent the basic interacting parameters are given in Table 1. Each variable is measured with respect to a given hour and direction of travel.

Quality of Traffic Service—Of the many available measures of quality of traffic service (6), unit travel time was considered to be the most appropriate. The Highway Capacity Manual (5) recommends the use of average overall travel speed in evaluating capacity and levels of service of urban arterials. Unit travel time as used in this study is simply the reciprocal of average overall travel speed. Unit travel time is also consistent with the units of the selected roadside characteristic variables.

Level of Land Access—In general, the traffic delay related to roadside development is caused by turning movements into and out of access points such as driveways and intersections. Because of this, any measure of the amount of abutting land use activity should account for the number of entering and exiting traffic movements over some time frame.

Several trip generation studies of specific land uses have been and are being undertaken to provide this type of information (1, 4, 8, 9). However, because of the wide range of conditions under which field studies or interviews have been conducted and the differences in classification of specific uses, there exists a substantial variation in reported rates for each land use classification. These difficulties notwithstanding, the average number of daily trip ends per mile (the sum of all entering and exiting traffic movements including intersections) was selected as the first measure of level of land access to be examined.

Trip generation studies have also shown that the number of trips generated by a given land use activity is a function of its type and size. Because commercial uses, as opposed to other land uses, are the major generators of roadside traffic over extended periods of time, the amount of commercial floor area adjacent to a given roadway was identified as a second measure of level of land access. Although this variable is intuitively less satisfactory than a trip generation rate, it can be measured and estimated with greater reliability.

Another measure of level of land access is simply a disaggregation of commercial activity into two classifications: retail and office (or service) commercial. The latter two variables require additional data, but they should more accurately reflect actual levels of trip generation. Because the three floor-area land access variables could not account for the delaying effect of intersection movements, the number of intersections per mile was included as a complementary variable for both sets of floor-area per-mile variables.

It was apparent that the potential delay to movement along a given arterial is influenced by the interaction between the adjacent land use activities and the respective directional traffic flows. In effect, the adjacent land use activities attract turning movements, and each directional flow produces turning movements in proportion to its total volume. Figure 1 shows this interaction for the general case. The figure shows the possible vehicular movements into and out of land uses abutting a section of arterial roadway. The respective directional flows are V1 and V2, and the adjacent land access variables are denoted by LA1 and LA2.

In order to account for the composite effect of abutting land use and traffic volume on delay to through traffic, the respective land access variables, LA1 and LA2, were weighted by those directional flows that might produce delaying turning movements with respect to a selected direction of travel. Thus, for travel in the direction of flow V1, the weighted measure of level of land access, $\overline{LA1}$, was expressed as

$$\overline{LA1} = LA1\ (V1 + V2) + LA2\ (V1) \tag{1}$$

As shown by this equation, delaying turning movements to or from a near-side land use activity, LA1, could be produced by traffic moving in either direction. However, turning movements to or from a far-side land use activity, LA2, would only cause delay to flow V1 if they were produced by flow V1.

As a matter of convenience, a weighting of unity for the near-side land access variable, LA1, was obtained by dividing the right-hand side of Eq. 1 as follows:

$$\overline{LA1} = LA1 + \left(\frac{V1}{V1 + V2}\right) LA2 \tag{2}$$

The resulting weighting factor, V1/(V1 + V2), is numerically equivalent to the percentage of the total arterial traffic flow that is moving in the selected direction of travel. Each of the land access variables identified for analysis was then weighted using Eq. 2.

Traffic Characteristics—This parameter can be defined in terms of trip characteristics and flow characteristics. Trip characteristics include factors such as trip purpose, trip length, and time of trip. Flow characteristics can be defined in terms of volume, speed, density, and other quality of service measures.

The trip characteristics of those drivers using a given arterial were not quantified or directly accounted for. However, they were indirectly considered by stratifying the sample data with respect to the a.m., p.m., and noon peak hours and the a.m. and p.m. off-peak hours. It has generally been found that the a.m. peak hour consists primarily of work trips, the p.m. peak hour includes both shopping trips and work trips, and the noon and off-peak hours are characterized by a mixture of shopping, social-recreational, and work trips.

Because quality of traffic service as measured by unit travel time was the dependent variable of interest, volume was the only traffic flow characteristic to be selected. Directional distribution does enter the analysis indirectly as the weighting factor for the level of land access variables.

Roadway Characteristics—The single roadway characteristic directly considered as an independent variable was speed limit. The influence of other roadway features was controlled through selection of the study sites. For example, an arterial was chosen for study only if it was a tangent, level roadway with two lanes per direction of travel and no median. In order to study the relation between unit travel time and level of land access more readily, the sample arterials were also required to have widely spaced signalized intersections. Where a signalized intersection did occur and interrupted flow conditions existed, the section containing the traffic signal and its estimated zone of influence (500 to 1,000 ft along each approach) was deleted.

A variable that was given much consideration but not included was roadway capacity. The capacity of an urban arterial is based in large part on the volume of vehicles capable of moving through a signalized intersection (5). Because signalized intersections were excluded from the study, intersection capacity at various points along an arterial was not judged to be an appropriate variable.

Data Collection

The essential characteristics of the three sites selected for analysis are given in Table 2. Many additional locations were discarded for one or more of the following reasons: (a) absence of commercial development along the roadside, (b) presence of closely spaced traffic signals or other bottleneck locations, (c) substandard roadway alignment, and (d) controlled access to roadside development.

Data collection began during the summer of 1971. Aerial photographs were used to prepare strip maps of each arterial showing the number of lanes, intersecting streets, access points, and land uses with direct access to the arterial. Each arterial was then divided into a number of sections. The basis for the location of a control point delineating the beginning or end of a section was twofold. First, control points were selected to represent demarcations in type and intensity of land use development along the arterial. Second, the length of the sections was kept generally uniform, approximately $^1/_{10}$ to $^3/_{10}$ mile long.

A plot of traffic volume versus time of day for each arterial was analyzed to determine characteristic peak and off-peak hours. Five time periods, 7:15 a.m. to 8:15 a.m., 10:00 a.m. to 11:00 a.m., 12:00 noon to 1:00 p.m., 2:00 p.m. to 3:00 p.m., and 4:15 p.m. to 5:15 p.m., were selected for study. A total of 12 travel time runs were then made on various weekdays for each arterial, hour, and direction of travel using the "average-car" method (2). When making these runs, elapsed times were recorded as each control point delineating a section was passed. The total sample thus consisted of travel time data along 56 arterial roadway sections for each of the five 1-hour periods.

Trip generation data compiled from previously published research investigations (1, 4, 8, 9) were utilized for the study sites. The selected trip generation rates given in Table 3 were expressed in average daily trips per 1,000 square feet of gross floor area for commercial and industrial uses, per student for institutions, and per dwelling unit for residential uses. Land use data for the study sites were obtained directly from the aerial photographs or by field measurements. Average daily trip ends on local streets that intersected the study arterials, for which no recent volume count was available, were estimated by considering the surrounding land use, local street pattern, street function, and volumes carried by similar streets in the area.

Data Analysis

Multiple linear regression analysis was used to test several travel time models. Each one was linear in nature and of the general form

$$Y = a + \sum_{i=1}^{n} b_i x_i \qquad (3)$$

where

Y = unit travel time for given hour, section, and direction of travel;
x_i = influencing variable;
n = number of influencing variables; and
a, b_i = regression coefficients.

The quality of a model was determined by use of statistics output by a stepwise regression analysis computer program. These included the mean, standard deviation, and correlation coefficients for each variable and the coefficient of determination for the model itself.

A test of significance at the 10 percent level was made as each independent variable entered the equation. These significance tests allowed deletion of those variables that did not measurably contribute to the variance explanation of the model.

Table 1. Variables selected for analysis.

Parameter	Symbol	Variable
Quality of traffic service	UT	Unit travel time, minutes per mile
Level of land access	WTRIPS	Weighted trip ends, thousands per mile for an average day
	WCOMFA	Weighted commercial floor area, thousands of square feet per mile
	WRETFA	Weighted retail floor area, thousands of square feet per mile
	WOFFFA	Weighted office floor area, thousands of square feet per mile
	WINTR	Weighted number of intersections per mile
Traffic characteristics	V	Volume, vehicles per hour
Roadway characteristics	SPEEDL	Speed limit, miles per hour

Table 2. Characteristics of study arterials.

Arterial	Overall Length (mile)	Number of Sections	Length of Sections (mile)	Number of Lanes	Lane Width (ft)	Speed Limit (mph)	Curb Parking	Average Weekday Traffic Volume
Monona Drive	1.97	22	0.08 to 0.23	4	12	30	No	12,270 to 15,760
Sherman Avenue	1.27	14	0.11 to 0.19	4	11	25, 35	No	9,680 to 13,720
University Avenue	2.01	20	0.11 to 0.30	4	11	30, 40	No	12,110 to 20,170

Figure 1. Generalized turning movements along an arterial roadway.

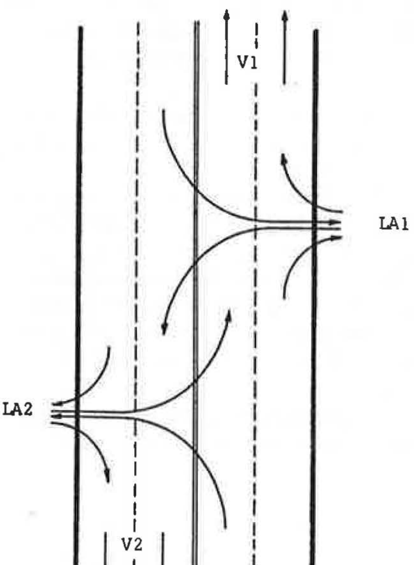

Table 3. Selected daily trip generation rates.

Land Use and Density Unit	Vehicle Trip Ends per Unit: Range	Typical
Residential (dwelling)		
Single-family	7.0 to 12.0	9.0
Apartments	3.0 to 7.9	6.0
Retail commercial (floor area, 1,000 square feet)		
Grocery store	17.6 to 43.4	30.5
Supermarket	70.0 to 240.0	130.0
Furniture store	0.6 to 13.4	5.6
Variety store	9.8 to 18.4	14.4
Drug store	19.0 to 99.8	43.5
Clothing store	10.4 to 55.0	31.3
Hardware store	21.6 to 37.4	29.5
Bank	5.8 to 188.0	61.5
Drive-in restaurant	1,160.0 to 3,260.0	1,160.0
Community shopping center	40.0 to 81.0	58.0
Highway service commercial (floor area, 1,000 square feet)		
Automobile sales and service	8.8 to 10.2	9.5
Service station	4.0 to 12.0	10.0
Motel	4.0 to 12.0	10.0
Office commercial (floor area, 1,000 square feet)		
General	1.6 to 60.0	14.0
Medical office	31.0 to 53.0	34.0
Post office	6.8 to 171.0	20.0
Library	56.6 to 62.4	59.6
Industrial (floor area, 1,000 square feet)		
Light	0.2 to 1.0	0.6
Institutional (student)		
Elementary school	0.4 to 1.0	0.8
High school	1.1 to 2.1	1.4
Recreation (acre)		
Golf course	2.0 to 10.0	8.0

RESULTS

Summary statistics for each of the study variables are given in Table 4. The difference in the means and standard deviations of the land access variables from one hour to another is due to the variation of the weighting factor.

Preliminary analysis of the data revealed that unit travel time was not significantly influenced by traffic volume for the study conditions. This was not totally surprising. The Highway Capacity Manual (5) indicates that, in general, as the volume-capacity ratio of an urban arterial increases up to approximately 0.8, there is only a slight reduction in average overall travel speed. Instead, at locations beyond the influence of a signalized intersection, average travel speed tends to be affected primarily by the posted speed limit and the level of marginal and intersectional friction. In light of these observations, hourly volume was deleted from further analysis. It should be emphasized, however, that the lack of a meaningful and statistically significant relation between travel time and traffic volume for the study sites does not justify the conclusion that traffic volume has no influence on average travel speeds along urban arterials. It would be essential to undertake additional research over a wider variety of traffic flow conditions before the actual relation could be reliably established.

The first travel time model to be tested used the number of weighted trip ends per mile as the measure of land access and speed limit as the controlling traffic flow parameter:

$$UT = a + b(WTRIPS) + c(SPEEDL) \quad (4)$$

The resulting regression coefficients and the coefficient of determination (R^2) are given in Table 5 for each of the five time periods studied. The absence of a coefficient for any variable during a given hour indicates that the variable was not significant at the 10 percent level.

As might be expected, the most significant variable during any 1 of the 5 hours was speed limit. The negative regression coefficients show that an increase in speed limit generally brings about a corresponding decrease in overall travel time.

The number of weighted trip ends was directly related to unit travel time during the a.m. and p.m. off-peak hours and the p.m. peak hour (and only slightly insignificant during the noon hour). This appears reasonable because most commercial uses are closed during the morning peak hour, whereas shopping activity usually declines over the noon hour. The values of the regression coefficients for weighted trip ends indicate that roadside development creates less interference to through traffic during the morning than in the afternoon. This is most likely a reflection of the greater amount of shopping and business activity taking place in the afternoon.

The second travel time model to be tested used weighted commercial floor area per mile and number of intersections per mile as measures of level of land access and speed limit as the controlling traffic flow parameter:

$$UT = a + b(WCOMFA) + c(WINTR) + d(SPEEDL) \quad (5)$$

Table 6 gives the resulting statistics for each of the five time periods studied. The absence of a coefficient for any variable during a given hour indicates that the variable was not significant at the 10 percent level.

Speed limit again proved to be the most significant variable during the 5 hours of study. The regression coefficients were negative, indicating the inverse nature of the relation between speed limit and unit travel time.

The weighted commercial floor area variable was significant in all but the a.m. peak hour. As noted before, this reflects the fact that few businesses are open at that time of day. The regression coefficients again indicate that roadside development has its greatest influence on traffic flow during the afternoon hours.

Weighted number of intersections per mile was significant during each hour except the afternoon off-peak (when it was only slightly insignificant). The regression coefficients suggest that turning movements from intersections tend to become more of a delay problem over the noon hour and during the afternoon peak hour than during the remainder of the day.

The final travel time model to be tested combined the weighted number of intersections per mile with a breakdown of commercial floor area into two categories: weighted retail floor area per mile and weighted office floor area per mile. Speed limit again represented the traffic flow parameter:

$$UT = a + b(WRETFA) + c(WOFFFA) + d(WINTR) + e(SPEEDL) \quad (6)$$

Table 7 gives the resulting regression coefficients and statistics. The absence of a coefficient indicates that the variable was not significant at the 10 percent level. Once again, speed limit had the expected inverse relation with unit travel time.

The separation of commercial floor area into retail and office components yielded a significant increase in variance explanation for the morning peak hour but only minimal improvements for the remaining time periods. The regression coefficients suggest that the major cause of roadside friction during the morning peak hour is commercial establishments. This may be associated with the high percentage of work trips occurring during this hour and the fact that office and professional services begin their activities relatively early in the morning.

Weighted office floor area per mile was the only significant land use variable during the noon hour. This is probably because of the predominance of noon-hour lunch trips with respect to shopping trips. However, during the evening peak hour, retail land uses were the significant activities affecting unit travel time. This would indicate the importance of the many shopping-to-home trips at this time of day. During the two off-peak hours, both retail and office activities proved to be significant causes of delay to through traffic.

Weighted number of intersections per mile was significant at all times except the afternoon off-peak hour. The values of the coefficients indicate that the effect of intersection turning movements tends to peak during the evening rush hour. This would reflect the large number of trips destined for residential areas at that time of day.

CONCLUSIONS

Theoretically, the model containing weighted trip ends per mile as the land access variable should offer the best explanation of the variance in delay to through traffic. This is because trip generation rates directly reflect the entering and exiting traffic movements that actually cause delays. As given in Table 5, the variance explanation for the sample data ranged from a low of 36 percent during the morning peak hour to a high of 51 percent during the afternoon off-peak hour. However, the weighted trip-ends-per-mile variable was only significant in 3 of the 5 hours studied. The reason for these results can probably be attributed to the difficulties in estimating trip generation rates for specific sites based on very generalized data for a broad range of conditions. Nevertheless, the potential usefulness of these data certainly warrants further study of trip generation characteristics of individual land use activities.

The combination of weighted commercial floor area per mile and number of intersections per mile as the measure of level of land access along an arterial offered a measurable improvement in the variance explanation of the travel time models. Table 6 gives a low value of 41 percent during the morning peak hour and values between 50 and 55 percent during the remaining hours. In addition, the commercial floor area variable was significant during all hours except the morning peak. These improvements can be attributed to the strong relation between trip generation and the gross floor area of commercial activities. Thus, the results of the statistical analysis suggest that weighted commercial floor area per mile can be utilized as an acceptable and easily obtained measure of level of land access along arterial roadways.

The final land access parameter to be tested was the combination of weighted retail floor area per mile, weighted office floor area per mile, and weighted number of intersections per mile. Retail and office floor area was simply a dichotomous classification of commercial floor area. The most noticeable improvement in variance explanation

Table 4. Descriptive statistics for the 56 study sections.

	Hour									
	7:15 to 8:15 a.m.		10 to 11 a.m.		12 to 1 p.m.		2 to 3 p.m.		4:15 to 5:15 p.m.	
Variable	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
UT	1.71	0.16	1.74	0.18	1.77	0.19	1.73	0.19	1.78	0.23
WTRIPS	16.8	17.9	16.7	17.5	15.6	16.2	16.5	17.4	16.4	17.4
WCOMFA	154.0	260.0	150.0	239.0	145.0	238.0	149.0	235.0	147.0	231.0
WRETFA	137.0	254.0	133.0	232.0	128.0	231.0	131.0	228.0	130.0	224.0
WOFFFA	17.0	29.0	17.0	28.0	17.0	28.0	17.0	28.0	17.0	28.0
WINTR	8.2	7.6	8.0	7.4	7.7	7.0	7.9	7.4	7.7	7.4
V	610.0	352.0	375.0	93.0	473.0	96.0	442.0	117.0	712.0	266.0
SPEEDL	31.3	5.2	31.3	5.2	31.3	5.2	31.3	5.2	31.3	5.2

Table 5. Regression coefficients and statistics for Eq. 4.

	Factor			
Hour	a	$b \times 10^{-3}$	$c \times 10^{-2}$	R^2
7:15 to 8:15 a.m.	2.29	—	-1.87	0.36
10 to 11 a.m.	2.36	1.95	-2.08	0.43
12 to 1 p.m.	2.57	—	-2.58	0.47
2 to 3 p.m.	2.34	3.45	-2.12	0.51
4:15 to 5:15 p.m.	2.52	3.90	-2.58	0.49

Table 6. Regression coefficients and statistics for Eq. 5.

	Factor				
Hour	a	$b \times 10^{-4}$	$c \times 10^{-3}$	$d \times 10^{-2}$	R^2
7:15 to 8:15 a.m.	2.30	—	4.65	-2.03	0.41
10 to 11 a.m.	2.34	2.12	5.66	-2.17	0.52
12 to 1 p.m.	2.51	1.49	6.22	-2.61	0.55
2 to 3 p.m.	2.36	2.44	—	-2.11	0.50
4:15 to 5:15 p.m.	2.55	2.99	6.89	-2.76	0.54

Table 7. Regression coefficients and statistics for Eq. 6.

	Factor					
Hour	a	$b \times 10^{-4}$	$c \times 10^{-3}$	$d \times 10^{-3}$	$e \times 10^{-2}$	R^2
7:15 to 8:15 a.m.	2.18	—	1.86	3.91	-1.73	0.51
10 to 11 a.m.	2.29	1.76	1.36	5.22	-2.03	0.55
12 to 1 p.m.	2.50	—	1.39	5.43	-2.56	0.55
2 to 3 p.m.	2.30	2.04	1.42	—	-1.98	0.53
4:15 to 5:15 p.m.	2.57	2.94	—	7.00	-2.81	0.54

was again during the morning peak hour. The information given in Table 7 shows that this model was able to explain between 51 and 55 percent of the variation in unit travel time for the study conditions. The breakdown of commercial floor area into retail and office components did provide a better understanding of the roadside development-traffic service interrelation by revealing which types of commercial uses were significant during which hours. However, from the standpoint of reliably estimating unit travel time, the disaggregation of commercial floor area is probably an unnecessary refinement.

A comment is in order regarding the weighting of the land access measures. The weighting scheme was hypothesized prior to the analysis, and no attempt was made to statistically test the suitability of unweighted measures. Nevertheless, intuitively and in view of the results of the statistical modeling, the weighting scheme would appear to be justified. Certainly, further investigation under a wider variety of locations and conditions would be most desirable.

In summary, this research has shown the importance of roadside development as a constraint on the quality of traffic service provided by urban arterials. Furthermore, the travel time models that were developed can offer a starting point for the systematic evaluation of the consequences of alternative development proposals. Such a procedure could allow local engineers, planners, and public officials to arrive at better land use control decisions in areas of new urban growth.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the National Science Foundation and the cooperation of the city of Madison Transportation Department, Traffic Engineering Division, for making this study possible.

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