Effects of Aging and Motorization on Travel Behavior: An Exploration

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It is hypothesized that the age of a person during intense motorization of his environment influences his perceptions, habits, and expectations about transportation throughout his lifetime. Thus successive age groups of individuals form cohorts, and the travel behavior of each cohort as it ages may be very different from that of other cohorts as they age. A paradigm of cohort, age, and time effects is proposed to sort out the effects of motorization and aging on travel behavior. An analytical framework for analyzing these effects using transportation survey data from several points in time is developed. Data from origin-destination studies from Rochester, New York, for 1963 and 1974 are analyzed by log-linear models of multidimensional contingency tables. Results of the analysis indicate that the effects of age on an individual's mobility vary across cohorts. The implications of cohort-aging effects on forecasting travel behavior of future elderly populations are discussed.

Those over the age of 65 are the fastest-growing portion of the population of the United States. Census projections estimate that by the year 2000 this group will make up 13 percent of the population, and by 2030 the percentage will increase to 21 percent *(1)*. It is inevitable that the well-being of elderly populations will have increasing implications for the well-being of American society as a whole. Because transportation is essential for the pursuit of daily activities and for well-being, it is critical that planners and policy makers be able to assess the transportation needs of future elderly populations.

Results are reported of some thinking about the effects of age on travel needs and the effects of motorization on travel habits and expectations. It is proposed that motorization has formed cohorts of individuals with respect to automobile use and it is this distinction that is the key to predicting future travel behavior. A paradigm of cohort, age, and time effects, proposed to sort out the influences of aging and motorization on travel behavior, is used to explore the effects of age and aging on travel observations. The ultimate goal of this effort is to contribute toward the development of practical and improved procedures to determine the mobility trends of future elderly populations.

The argument for and the importance of considering motorization as a source of a cohort phenomenon in travel behavior are presented in the following section. Hypotheses and conjectures about the effects of motorization and aging on travel behavior are developed next. Then an analytical framework for analysis of cohort, age, and time effects is proposed. As an initial application and test of the framework, the ability of individuals to use automobiles is studied by using data from origin-destination surveys from the same urban area from two different time periods. The results are summarized and the implications and research directions are discussed.

Before the discussion, the definition of several key terms used in this study is appropriate. A *cohort* is a group of individuals defined by a common characteristic. In this research the most frequently used variable for demarcating cohorts, date of birth, is used. *Mobility* in this research is defined as the ability of individuals to use the automobile-oriented transportation system and is selected as the criterion measure of travel behavior. *Cohort effects* on travel behavior are defined to be enduring intercohort distinctions that are attributable to the common "imprinting" of cohort members. *Time effects* are fluctuations in the data that are due to idiosyncratic events or circumstances occurring at particular time points. *Age effects* refer to long-term patterns associated with the progression through life cycles, though not necessarily with aging per se. To distinguish between age and aging effects, the term "age effect" will be used when an effect can be well defined given the age alone and the term "aging effect" will be used when the effect is associated with the process of aging and therefore can be defined only when a cohort of individuals is observed at different points in time.

MOTORIZATION AND COHORTS

Motorization is the spread across a population of the ownership and use of the automobile as a consumer technology. The process has been ongoing in the United States since the early part of this century. In particular, the rapid pace of motorization after World War II is evident from statistics. For example, in 1950, 41 percent of households were without a car; by 1980, 87 percent of U.S. households had at least one car available. The percentage of households with two or more cars increased from a mere 7 percent to 52 percent during the same time period *(2)*. Today about 85 percent of the adult population is licensed to drive *(3)*, and the percentage of license holders among those between 25 and 35 years of age reaches 96 percent.

The increases in automobile ownership and driver licensing have leveled off, and today motorization in the United States is considered to be at a mature stage *(4)*. Nonetheless it is indisputable that the expansion of the highway network and growth of the suburb, which took place as part of motorization, have irreversibly converted urban land use and infrastructure to an automobile-based system. By the same token, it is conceivable

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that motorization has irreversibly affected the travel behavior and attitudes of Americans.

Another aspect of motorization is that the acquisition of licenses to drive automobiles was not uniform across the population. Younger and more affluent adults were the first to drive. For example, in 1940 only 25 percent of all drivers in the United States were 40 years old or older and only 1.7 percent were over 65 *(5)*. In 1983 about 45 percent of the drivers were over 40, about 24 percent were over 55, and 11 percent were over 65. Thus, many of today's elderly, and even more of the elderly of the past, may never have acquired a license to drive. A large portion of the future elderly, on the contrary, has had a lifestyle in which automobiles were the central device for pursuing daily activities *(6)*.

It is suggested that the process of motorization "imprinted" travel habits and expectations on successive groups and in effect formed cohorts with respect to travel behavior. Those individuals who were in their twenties and thirties during the intense motorization process of the 1950s and 1960s are now reaching their fifties and sixties and will soon reach the elderly category.

An increase in car ownership and use among older Americans is becoming evident, and this trend is expected to continue as new cohorts of the population enter the elderly category. FHWA estimates that by 2000, 28 percent of drivers will be over 55 and by 2050 this percentage will be 39 percent *(7)*. It is certain that the well-recognized problem of the aging driver will intensify in coming years.

Solutions to this problem seem to call for extensive modification of the vehicle-highway-driver system and improved public transit services for the elderly. A critical element in such an effort is the understanding of the context in which older people make trips, that is, understanding of their needs and desire for travel, and rigorous quantification of the spatial and temporal characteristics of their travel patterns.

Studies of the elderly as transportation disadvantaged (*8*, pp. 23–41; *9*), in particular, have examined the elderly with low incomes, low automobile availability, or with physical impairments. There appear to be consistent empirical indications from these and other studies that older individuals make fewer and shorter trips and that their mobility levels are far below those of the rest of the population *(10)*. This may be a result of age itself, or of physical impairment due to age, or of the inability to use the key component of the transportation system—the automobile.

Nonetheless, the current understanding of travel behavior and needs of the elderly is unfortunately limited. With the exception of the work by Wachs *(6)* and by Goodwin and Layzell (*11*, pp. 185–200), in which the idea of cohorts is connected with automobile and transit use, knowledge in the transportation planning field has been based on cross-sectional examination of travel patterns obtained from standard transportation planning surveys. This is also the case in studies of the elderly as transportation disadvantaged.

It is anticipated that the large future elderly population will be much more diversified with respect to income. Low car availability may have been in part a manifestation of the motorization-cohort effect and not an inherent characteristic of the elderly. Physical impairment may be an inevitable effect of age, but it may affect the future elderly later in life, if the numerous forecasts of the health and longevity of the new cohorts of elderly are to be believed.

From this viewpoint, it appears most appropriate for this study to adopt the cohort analysis, a set of methods for studying longitudinal change. First used in demography to examine generation effects on mortality *(12, 13)*, the cohort concept is used in epidemiology (*14; 15; 16*, pp. 151–227) and in the social sciences (*17*, pp. 215–239). The goal of cohort analysis is to assess the extent to which the variation in a criterion measure observed on cohorts over time is attributable to period, age, and cohort effects or possibly to their interactions. The analytical methods include a wide array of approaches, from simple examination of tabular displays to fairly rigorous multiple regressions and log-linear estimation procedures *(18–20)*.

In summary, most of what is known about the travel behavior of the elderly is based on observations made at one point in time. This is in line with the fact that the numerous planning studies conducted in the past took a static viewpoint toward motorization and travel behavior; the possibility that travel behavior was a dynamic process the characteristics of which may have been changing as motorization progressed was not considered. The characteristics of activity and travel of the elderly derived from a cross-sectional transportation survey, therefore, cannot be extrapolated to another time point unless travel behavior of population segments remains stable over time. This extrapolation is not reasonable because most large-scale transportation surveys were made during the time when urban areas in the United States were undergoing rapid motorization. Therefore, the findings of these studies cannot be simply applied to the forecasting of future transportation needs and behavior of the elderly without a sorting out of the effects of mobility habits, expectations, and capabilities.

CONJECTURES

It is reasonable to expect that those individuals who were young and just forming habits during the time of intense motorization acquired travel habits that are fundamentally different from those of individuals who were older during that period. Motorization may have had permanent impacts on urban residents' attitudes toward trip making, expectations for mobility, and formation of habitual trip patterns. It is hypothesized that the possible differences in perception, motivation, and habits that influence travel behavior are associated with the age of the person during the period when motorization progressed in his or her environment. Note that this in effect is a cohort effect on travel behavior.

Coupled to this cohort effect are the changes in travel behavior due to aging. It is expected that age has its own independent effect on travel behavior apart from the effects of retirement, changes in life cycle, and other events. Gelwicks *(21)* argues that the "lifespace," or the predominant locus of activities and settings of an individual in his normal activities, contracts as the person ages. This constriction, however, has not been rigorously quantified.

Furthermore, observed travel patterns also carry with them effects of the particular time at which the observations were made. This would include such phenomena as economic recessions, gasoline shortages, or the extent of motorization at that particular time. Note that the time effect (or period effect) uniformly influences all individuals in a cross section.

The following conjecture is proposed: time, age, and cohort effects are among the factors that influence travel behavior and needs of urban residents. The cohort effects arise because, it is hypothesized, motorization leaves a permanent imprint on an individual's travel behavior and attitudes, and therefore his or her travel behavior at any point in time is influenced by his age during the period of intense motorization.

This leads to the second conjecture: the effect of aging on travel behavior differs across cohorts. A given cohort may exhibit unique characteristics, not only in a static comparison with other cohorts within each cross section, but also in a dynamic comparison of behavior across cross sections. In other words, each cohort is unique in the way it ages. This is postulated because the permanent imprints of motorization on a cohort of individuals may combine with the effect of aging in a manner unique to the cohort. The counterhypothesis is that the effect of aging is uniform across cohorts. Proper identification of these effects is critical for predicting the travel behavior of future elderly populations as well as for understanding their travel needs.

Some clarification is due at this point about the hypothesis postulated earlier that the major component of cohort effects is caused by motorization. The cohort effects identified from transportation survey results will reflect not only the effects of motorization on habit formation but also those of any significant factors influencing cohorts of individuals. Although the authors strongly believe that the degree of motorization at the societal level at some past point in time is the central component of cohort effects on travel behavior, this will remain an assumption. In order to reduce the risk of being confounded by ecological fallacies, the concept of motorization at the individual level, which is assumed to condition the individual's short-term travel behavior, will be adopted.

The second point to be noted here is that the factor more directly contributing to the formation of an individual's travel habits may be the initial acquisition of an automobile and driver's license and the history of car ownership at the individual or household level, not the extent of motorization at the societal level. This hypothesis, although very plausible, cannot be tested by using repeated cross-sectional observations with independent sampling, which is the case for the data set available in this study. In the discussion of this study, therefore, the effects of history are treated as random effects. The development of an automobile-oriented infrastructure and relocation of opportunities took place at the societal level, and these societal changes are believed to have influenced a cohort in a certain manner despite the obvious variations within the cohort with respect to car and license acquisition.

ANALYTICAL FRAMEWORK

It is appropriate to view observed daily travel behavior as a result of short-term travel choices that are conditioned on long-term mobility choices *(22)*. The latter are the decisions concerning residential location, car ownership, and driver's license holding. These decisions collectively set an individual's capability to use the automobile-based transportation system, which is defined as the individual's mobility level. The mobility level thus sets the conditions for the individual's decisions associated with daily activity and travel behavior. Therefore, age, cohort, and time may have measurable effects on the individual's mobility level as well as on his or her daily travel patterns, given the mobility level.

Motorization and suburbanization at the societal level are an aggregate of individuals' decisions as to license holding, car ownership and use, and residential location. In this sense an individual's mobility level can be viewed as an indicator of motorization at the individual level, or as "microlevel motorization." Similarly, the distribution of mobility levels within a cohort can serve as an indicator of the degree of motorization of that cohort. Unlike the degree of motorization at the societal level (or background motorization), the degree of motorization defined at the individual level is observable from available transportation survey data.

Detailed information on travel behavior is available from origin-destination surveys of large-scale transportation studies carried out in most metropolitan areas of the United States since the 1950s. During the last three decades most metropolitan areas updated their data bases, and records of travel patterns are often available for two or more points in time in the same metropolitan area. These sets of records contain a wealth of information about changes in travel behavior that has been virtually untapped.

Methods of cohort analysis *(6, 18–20, 23, 24)* and other multivariate statistical techniques, in particular the log-linear model of multidimensional classification table analysis *(25)*, can be used to separate out the effects of age, cohort, and time on travel behavior. Various formulations of log-linear models can be applied in order to represent behavioral hypotheses to be tested. Examples of such formulations are found in the next section.

In an empirical analysis any other classifiers that are (or are suspected of being) important should be included in the analyses. This would account for the internal sample distribution and any "fact-of-life" interdependencies among the classifiers, and would help avoid pitfalls such as Simpson's paradox *(26)*.

EMPIRICAL ANALYSIS

The model development effort in this pilot study is directed by both theoretical and empirical explorations. Models are theoretically developed to represent specific hypotheses, and the hypotheses are then tested by estimating the corresponding models. In this paper models that represent the hypotheses of uniform aging effect across cohorts and of stable age effects are discussed. The statistical package used is the PDP-11 version of BMDP Statistical Software.

Observations from 1963 and 1974 origin-destination survey data from Rochester, New York, form the data base. The original trip records are examined for consistency and aggregated into person records *(4, 27)*. Only records of those over 21 years of age are used in this exercise.

The observation is organized into two sets of tables—one formulated by using age categories and the other by using cohort categories. Log-linear models developed on the first set of tables assume the presence of age effects on mobility, whereas those developed on the second assume the presence of aging effects.

Individuals in the sample are classified by age into five categories for each time period. Each age category from 1963

TABLE 1 ROCHESTER, NEW YORK, SAMPLE CLASSIFIED BY YEAR, AGE, AND COHORT

	No. in Sample by Age						
Year	21–31	32–42	43–53	54–64	64–74	75–85	Total
1963	2,551	4,959	3,107	2,105	1,668		14,390
		$^aC_1$	C_2	C_3	C_4	C_5	
1974		647	657	584	376	182	2,446

^aC_n refers to the *n*th cohort category.

together with the next higher age category from 1974 form a cohort, resulting in five cohort groups for analysis. Table 1 shows the sample size classified by age and cohort group. (There are six age categories altogether, but the individuals in the youngest category in 1974 and those in the oldest category in 1963 are not used in the analysis so that the identical set of individuals will be included in both age and cohort tabulations.)

The following three categories are used to represent the level of mobility of each individual:

Level 1: no car available, not licensed to drive;
Level 2: no car available, licensed to drive; or car available, not licensed to drive; and
Level 3: car available, licensed to drive.

In order to adequately account for the heterogeneity across individuals in the sample, employment and sex are included in this analysis as additional classifiers of individuals. No additional classifiers are examined in this exploratory analysis of the effect of aging.

Variables common to both sets of tabulations are

M = mobility level (the response variable, defined in previous section),
T = time (year, i.e., 1963, 1974),
E = employment (employed, not employed), and
S = sex (male, female).

Age, used in the first set of models, is denoted by A, and cohort, used in the second set, by C. Their categories are as defined in Table 1. Individuals older than 75 in 1963 and those younger than 31 in 1974 are eliminated from the tabulation in order to have an identical set of individuals in both age and cohort tabulations.

Test of Uniform-Aging-Effect Hypothesis

In a table formulated by using cohort categories, the differences in cohort behavior between two time points can be interpreted as representing the effect of aging. In other words, the interaction between time (T) and cohort mobility (MC) can be used as a measure of the aging effect of that cohort. Then the assumption of uniform aging can be obtained by dropping the time–cohort–mobility interaction effect. Starting from a saturated model (the model that contains all possible effects and interactions, *MCEST*), all terms that involve *MCT* are eliminated and (*MEST, CEST, MCES*) is obtained as the model representing the hypothesis of the uniform aging effect. First the term *MCEST* is eliminated, which results in a model with 5 four-way interaction terms (*MCES, MCET, MCST, MEST, CEST*). *MCET* and *MCST*, which contain *MCT*, are removed next to yield the previous model, which will be called a saturated-uniform-aging-effect model because it comprises all interaction effects that do not involve *MCT*.

This saturated-uniform-aging-effect model, however, does not fit the observation. As indicated in Table 2, the model yields a χ^2-statistic of 76.35 with 32 degrees of freedom (df). The discrepancy between the observation and the expected frequency (or prediction) by the model is significant at $\alpha < 0.00005$. Clearly the hypothesis of uniform aging must be rejected and the term *MCT* must be introduced into the model.

TABLE 2 GOODNESS OF FIT OF ALTERNATIVE LOG-LINEAR MODELS: COHORT FORMULATION

Model	Description	χ^2	Degrees of Freedom	α
(*MEST, CEST, CMES*)	Saturated-uniform-aging model	76.35	32	<0.00005
(*CEST, MST, MCT, CMES*)	Best cohort-aging model	41.63	28	0.0470

Table 2 also shows the best cohort-aging model selected. The model includes *MST* and *MCT* in place of *MEST* (note that the degrees of freedom in the best model decrease because *MCT* alone consumes larger degrees of freedom than *MEST*). The inclusion of *EST* (subordinated in *CEST*) and exclusion of *MEST* in the best model imply that the association of mobility, employment, and sex did not vary over time. On the other hand, the association between mobility and cohort did vary over time, as indicated by the inclusion of *MCT*. The five cohorts of this analysis did not age uniformly with respect to mobility between the two points.

The association between cohort and mobility as revealed by the best model is presented in Table 3 (effects of interaction terms are shown in the table in terms of the distribution of mobility levels as revealed by the interaction terms). The cohort–mobility interaction clearly shows that individuals in younger cohorts tend to have higher car accessibility. Note that these interaction terms isolate the effects of the factors involved and present their pure effects.

The distribution obtained by superimposing the time–cohort–mobility effect onto the cohort–mobility effect demonstrates different patterns of aging effects on mobility across the cohorts. The two youngest cohorts (those 21 to 31 years old

TABLE 3 AGING EFFECTS AS REVEALED BY PERIOD–AGE–CAR ACCESSIBILITY INTERACTION EFFECTS

Period	Car Accessibility	Age 21–31	32–42	43–53	54–64	≥65
Age–Car Accessibility Interaction						
NA	Level 1 (low)	10.9	22.5	34.5	51.2	57.2
NA	Level 2	30.4	32.4	31.5	26.1	30.7
NA	Level 3 (high)	58.7	45.1	34.0	22.7	12.1
Period–Age–Car Accessibility Interaction[a]						
1963	Level 1 (low)	23.6	29.5	31.6	37.1	45.3
	Level 2	33.6	29.0	31.8	33.9	35.1
	Level 3 (high)	42.8	41.5	36.6	29.0	19.6
1974	Level 1 (low)	4.4	16.7	37.5	65.3	67.8
	Level 2	24.3	35.4	31.0	18.4	25.1
	Level 3 (high)	71.2	47.9	31.5	16.3	7.0

NOTE: NA = not applicable.
[a]Obtained by superimposing the period–age–car accessibility interaction effect on the age–car accessibility effect.

and 32 to 42 years old in 1963 age) show increased degrees of mobility in 1974, whereas the last two cohorts (54 to 64 and 75 to 85 years old) exhibit substantial decline in their microlevel motorization. The overall increase in car accessibility observed between the two time points *(4, 27)* is not evenly distributed across all cohorts, but is due to the increased car accessibility among individuals in younger cohorts.

Test of Fixed-Age-Effect Hypothesis

The saturated model of fixed age effect can be obtained by eliminating the interaction term *MAT* from the saturated model (*MAEST*) formulated for the five-way table based on the age categories. This yields (*MEST, AEST, MAES*) as a saturated model of fixed age effect. Fitting this model to the data leads to a good fit (χ^2 = 29.51, df = 24, α = 0.20) that supports the hypothesis of fixed age effect (Table 4). As the best age-based

TABLE 4 GOODNESS OF FIT OF ALTERNATIVE LOG-LINEAR MODELS: AGE FORMULATION

Model	Description	χ^2	Degrees of Freedom	α
(*MEST, AEST, AMES*)	Saturated age-period model	29.51	24	0.2016
(*EST, AST, AET, MET, AMES*)	Best age-period model	48.14	31	0.0255

model, a more parsimonious specification including a four-way interaction term (*MAES*) and 4 three-way interaction terms involving time (*EST, AST, AET,* and *MET*) is selected. The age–mobility relationship shown by this model is presented in Table 5, in which the same relationship—that the level of mobility is higher among younger individuals and lower among older individuals—is shown.

The stability of the age effect suggests that the aging effect on microlevel motorization can be represented as a shift to the next higher age category in the age–mobility table (Table 5). Table 6 shows this aging effect implied by the fixed-age-effect model. Comparison of Tables 3 and 6, however, clearly shows the difference between the aging effects derived from the two models. For example, the drastic increase in car accessibility observed for the youngest cohort between 1963 and 1974 cannot be represented as a shift from the 21–31-year age group to the 32–42-year age group as in Table 6.

TABLE 5 AGE EFFECTS AS REVEALED BY AGE–CAR ACCESSIBILITY INTERACTION EFFECTS

Car Accessibility	Age 21–31	32–42	43–53	54–64	≥65
Level 1 (low)	23.6	29.1	30.1	37.1	47.2
Level 2	33.1	28.1	34.5	33.1	34.3
Level 3 (high)	43.3	42.8	35.5	29.8	18.5

TABLE 6 AGING EFFECT DERIVED FROM THE UNIFORM-AGE MODEL

Period	Car Accessibility	Age 21–31	32–42	43–53	54–64	≥65
1963	Level 1 (low)	23.6	29.1	30.1	37.1	47.2
	Level 2	33.1	28.1	34.5	33.1	34.3
	Level 3 (high)	43.3	42.8	35.5	29.8	18.5
1974	Level 1 (low)	29.1	30.1	37.1	47.2	
	Level 2	28.1	34.5	33.1	34.3	
	Level 3 (high)	42.8	35.5	29.8	18.5	

It is difficult to determine which formulation is better on the basis of the available statistics because the two tables are prepared differently. No convenient procedure appears to exist for testing across models when they are developed for differently organized classification tables. However, inspection of the observed frequencies favors the cohort model. In the youngest cohort, the percentage of individuals in mobility Level 3 was 74.8 percent in 1963, which increased to 95.8 percent in 1974. This drastic increase in the observed frequency, which is evident in both cohort and age tabulations, is not captured by the age model in which the interaction term *MAT* is not significant.

The findings of this analysis indicate that motorization did not progress equally across the population. The younger generation has a much higher level of mobility than the older generation and can be considered to be much more motorized. Examining the results by sex showed definite differences in mobility levels between men and women for the older cohorts. Although there was an increase in mobility between the two time periods for all cohorts, the increases were much larger for men than for women. In particular, older nonworking women showed the smallest gains in mobility between the two time periods. The cohort of persons 21 to 31 years old did not exhibit much effect of sex on mobility. This particular cohort is now 43 to 53 years old, indicating that much different patterns of travel behavior can be expected from the future elderly than those observed for today's elderly.

IMPLICATIONS AND RESEARCH DIRECTIONS

The foregoing empirical analysis is a limited exercise, and more extensive analyses of the effects of age, cohort, and time are needed. Nonetheless, the results of this empirical analysis offer support for the concept of a cohort effect on individual mobility because the effects of aging on this measure were found to vary across cohorts, and further because a model based on age alone was unable to replicate the aging effects observed in origin-destination survey results.

An immediate and important extension of this research is the examination of the effects of age, cohort, and time on daily travel behavior indicators given the microlevel of motorization (e.g., number of trips made by individuals, time spent for travel, travel modes used, type of activities pursued outside the home, temporal and spatial distribution of activities and their locations, and structuring of a set of trips into trip chains). Microlevel motorization can be used as a control, and cohort effects that are identified could be an extraction of the travel habits unique to each cohort.

Such an analysis should indicate into which of the following four cases each effect falls. Identifying which case best represents the effect of age, cohort, or time is a crucial step for the prediction of travel behavior of future elderly populations because extrapolation of observation into the future is appropriate if and only if Case 4 proves to hold for cohort and age effects.

	Significance of Age, Cohort, or Time Effects			
	Case 1	*Case 2*	*Case 3*	*Case 4*
Microlevel motorization	Yes	Yes	No	No
Daily travel pattern	Yes	No	Yes	No

If cohort or time effects on travel patterns, given microlevel motorization, are significant, it would imply that the widely practiced approach in transportation planning will be inadequate and the future elderly will behave differently. Furthermore, significant effects on microlevel motorization would point to changes in car ownership and residential locations among future elderly populations. Answers to these questions can help to determine the travel characteristics and needs of future elderly populations and to infer their implications for transportation planning and policy development.

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