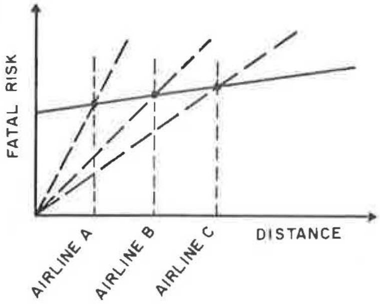
Figure 7. Comparisons among three airlines that have identical failure indices.



Clearly, then, when any two carriers within an individual mode are compared, one must consider not their basic or even conventional statistics, but rather their α_is as defined in the failure-index concept.

CONCLUSIONS

The failure index can be used to make clear and unambiguous modal cost comparisons. The actual case described in this paper was that of the individual passenger and fatalities only. If sufficient data were available, it would be possible to develop comparable graphs to illustrate fatality risks from the point of view of the operator and of society. These graphs would include deaths of crew members, bystanders, and others. If severity scales were assigned in some systematic way, one could then use future data to ascertain the relative merits of the several modes from the point of view of total severity and not just of fatality. One could then address the critical questions of allocating funds for improvement to the various modes on the basis of equalizing the risk of the individual passenger or assigning priorities to the modes on the basis of minimizing total severity. In actual fact, one would then deal not just with modal priorities but also with the priorities of treatment among all possibilities, irrespective of mode.

ACKNOWLEDGMENT

This paper is based on a dissertation submitted by J. Byun to the Department of Transportation Planning and Engineering, Polytechnic Institute of New York, in partial fulfillment of the requirements for the Ph.D. degree. The work was conducted in the Transportation Training and Research Center, Polytechnic Institute of New York, as an element of the University Research Program, U.S. Department of Transportation. This paper was prepared under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. government assumes no liability for its contents or the use thereof.

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Publication of this paper sponsored by Committee on Transportation System Safety.

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Changing Baseline in Transportation Safety: An Assessment of Some Key Factors

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Transportation accident experience depends on many factors, some very subtle. Although many countermeasures are introduced to enhance safety, it is also true that the accident experience can vary systematically over time even if no countermeasures are introduced. This variation in the baseline is investigated in this paper. How can the average condition vary if no new changes are introduced? Simply put, there are variations built into the total system—operators, roadway, and vehicles. Four major forces are considered in this paper: the changing age distribution of the automobile-driving population; the changing urban-rural balance; changes in modal trip lengths or vehicle types; and modal shifts induced by transportation system management actions. Each of these is found to have a significant effect (5-10 percent on the baseline), and other such forces can also exist. Clearly, it is not valid to explicitly or implicitly assume that the baseline does not change.

The development of a failure index (1) that can serve as a basis for comparing the relative safety of different modes is described in the previous paper in this Record. This paper uses that failure index and general indicators to study the apparent safety-record improvements that are induced by societal and other forces.

A number of forces are working in our society that

will alter an apparent safety record or aggregate safety statistics or the true safety history. It is important to identify the possible factors that can change the safety experience over time in predetermined ways without the introduction of new forces. That is, factors that cause the reference level or baseline to change without other modification of the system should be identified.

In the situations of interest here, even if no new improvements are made after a given date, safety records will still change thereafter. If a number of ineffective safety measures are undertaken in the future, the baseline will still change. If one does not appreciate that the baseline is changing, one will erroneously conclude that the ineffective actions are useful accident countermeasures.

To consider one example, note that recent automobile models are safer than those of 10 and even 5 years ago. If there were no further improvements in new models from the present time, the future fleet would still become safer as new automobiles replaced those 5-10 years old. This would, of necessity, have an impact on the safety measure of actual safety; the baseline would change.

Because the overall safety of a system depends on a number of factors, the apparent safety level will vary, depending on how these factors themselves vary. Thus, it is entirely possible for safety performance to change over time, for no other reason than that underlying influences are themselves changing. That is, the baseline changes.

When assessing the effect of any projected transportation improvement, it is important to factor out expected changes due to other, identifiable effects. This paper discusses several case studies of such effects:

1. Overall societal forces and trends—population aging and urban-rural split,
2. Changes of mode or within-mode characteristics, and
3. Effects of a transportation system management action.

These case studies are not exhaustive, but they are representative of the effects that exist, some of which are subtle and some of which are clear.

FAILURE INDEX

A trip on any mode can be considered to be a set of trips through distinct, identifiable environments that are linked together as represented in Figure 3 of the previous paper in this Record. Each environment (say, environment 2) can be traversed successfully with probability P_i or unsuccessfully with probability ($F_i = 1 - P_i$). In the latter case, a fatality or injury of severity S_i occurs.

A failure index (FI) can be constructed (2) as

$$FI = \sum_{i=1}^{N} S_i F_i \left(\prod_{k=1}^{i=1} P_k \right) \qquad (1)$$

By considering the available data, the case of fatality-only was calibrated for the failure index as viewed by the individual passenger. Because the S_is are all equal to some common value S (which can be set at unity), Equation 1 can be rewritten as

$$FI = S \left\{ 1 - \prod_{k=1}^{N} P_k \right\} \qquad (1a)$$

The probability P_k can be expressed as $\exp(-\beta_k)$ and then approximated by $(1 - \beta_k)$. Further manipulation gives the form

$$FI \cong A + B(\text{distance}) \qquad (2)$$

for most modes, where the constant A is associated with the trip terminals and has units of probability of fatality per trip and the constant B is associated with the en-route portion of the trip and has units of probability of fatality per unit distance.

The A- and B-values estimated for the various modes are summarized below, where B has units of fatalities per 15 000 km (24 000 miles); the FIs plotted from these estimates are shown in Figure 2 of the previous paper in this Record.

Mode	A	B
U.S. air carrier	0.80×10^{-6}	0.0034×10^{-4}
Local roads and streets (rural)		2.31×10^{-4}
Federal-aid primary roads (rural)		1.47×10^{-4}
Local roads and streets (urban)		0.72×10^{-4}
Federal-aid primary roads (urban)		0.60×10^{-4}
Passenger automobiles and taxis		0.96×10^{-4}
Passenger automobiles on turnpikes		0.65×10^{-4}
Buses (city)		0.20×10^{-4}
Intercity buses		0.06×10^{-4}
Railroad passenger trains		0.07×10^{-4}

Clearly, for certain distances, some modes have distinct safety advantages. These results are sometimes not consistent with conventional understandings of relative safety advantage, particularly of air. For instance, air is less safe than rail or intercity bus for trips of less than 2400 km (1500 miles), whereas it is often said to be the safest mode.

CASE 1: POPULATION AGING

It is well known that the population is aging and that coming decades will witness a steady growth in the relative percentage of older persons. At the same time, there is a known difference in relative frequency of accidents by age group. Figure 1, which is based on National Safety Council data (2), shows this relative frequency. There was a significant stability in this pattern over the 7-year period investigated (1969-1975).

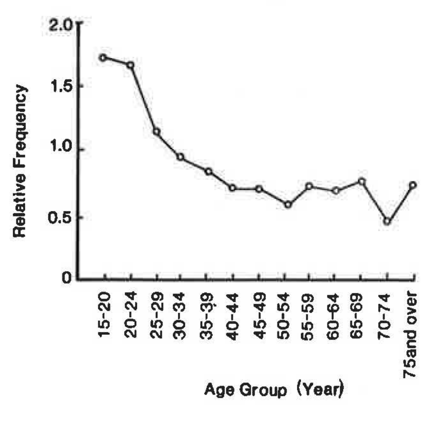
The ratio (R) between the relative motor-vehicle-accident frequency for year k, due only to population aging, and that for the base year 0, can be expressed as

$$R = AR^k/AR^0 \qquad (3)$$

where

AR^k = relative accident frequency for year k and
AR^0 = relative accident frequency for year 0.

Figure 1. Relative frequency of accidents in age group: involvement based on overall driving population.



The relative accident frequency for year k due to demographic change is

$$AR^k = \Sigma P_i^k Q_i^k a_i / \Sigma P_i^k Q_i^k \quad (4)$$

where

P_i^k = percentage of population in age group i in year k,
Q_i^k = percentage of population licensed in age group i in year k, and
a_i = relative motor-vehicle-accident frequency, due to driver age group i.

The percentage of population in each age group has been estimated by the U.S. Bureau of the Census for future years.

The percentage of the population within each age group that is licensed was estimated according to two scenarios: (a) the percentage in each group remains unchanged and (b) no licensed drivers give up their licenses as they age, so that the percentage in the older groups grows. The first scenario is conservative in that those who will be 60- to 65-year-old drivers in the late 1990s are now 40-45 years old and, to a greater extent than persons currently 60-65 years old, grew up with the automobile. It is more likely that they (and other age groups) will retain their licenses, thereby increasing the representation of older drivers in the licensed population.

Figure 2 compares the relative accident frequency AR^k with the 1975 base condition. Under either scenario, it is reasonable to expect a 10 percent decrease in accident frequency by the year 2000 simply because the population will be older.

CASE 2: URBAN-RURAL SPLIT

Two phenomena are worthy of note: (a) the traffic density in rural areas is increasing and (b) the ratio of urban vehicle travel to rural vehicle travel is increasing. Thus, more of the total vehicle travel is occurring in urban areas. At the same time, however, the amount of vehicle travel per kilometer of highway in rural areas is also increasing. These two forces will combine to affect the future accident history.

State-based data separated by urban and rural fatal-accident rates are available from the Federal Highway Administration (3) as are estimates of vehicle kilometers and kilometers of highway.

Traffic densities (vehicle kilometers per kilometer of highway) were computed and subjected to regression analysis. Figure 3 shows the results of the regression analysis—rural accident rates are statistically related to traffic density as defined herein, whereas no such relationship exists for urban accident rates.

$$f = 2.95 - 1.59\, d_k \quad \text{(rural)} \quad (5a)$$

and

$$f = 1.4 \quad \text{(urban)} \quad (5b)$$

where f = fatality rate (fatalities per 100 million vehicle kilometers) and d = density (million vehicle kilometers per highway kilometer). A level of significance of α = 0.05 was used.

Comparison of Figures 3a and 3b shows that the urban rate is significantly lower than the rural rate and that the two data clusters form a continuum; generally $d \leq 0.40$ for rural traffic and generally $d \geq 0.40$ for urban traffic.

Estimates for future urban and rural vehicle travel are given in Table 1 (4). The relative fatal risk due to traffic-density changes for the year k (R_k), based on the year 0, will be

$$R_k = \{[(M_k^r \times f_k^r) + (M_k^u \times f_k^u)]/(M_k^r + M_k^u)\} \div [(M_0^r \times f_0^r) + (M_0^u \times f_0^u)]/(M_0^r + M_0^u) \quad (6)$$

where

M_k^r and M_k^u = rural and urban, respectively, vehicle kilometers in year k;
M_0^r and M_0^u = rural and urban, respectively, vehicle kilometers in year 0;

Figure 2. Relative frequency of accidents in age group: involvement based on two scenarios of overall driving population.

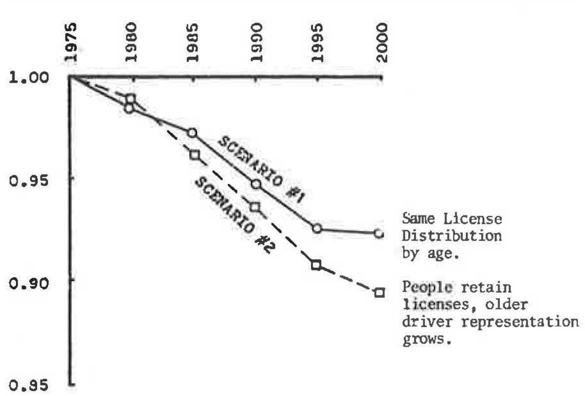


Figure 3. Relationship between fatal-accident rate and traffic density: (a) rural highways and (b) urban highways.

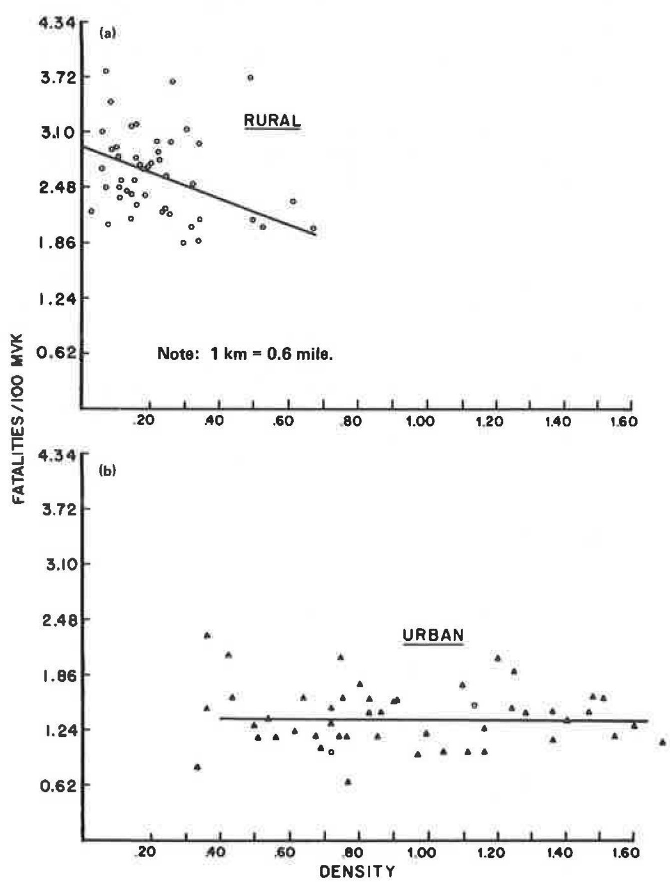


Table 1. Projections of highway travel.

Year	Automobile Travel (km billions) Rural Interstates	Main Rural Roads	Local Rural Roads	Urban Interstates	Urban Highways and Streets	Truck Travel (km billions)	Bus Travel (km billions)
1975	140.305	271.005	315.677	146.28	757.130	69.603	8.152
1976	146.129	267.413	314.125	154.602	773.452	71.568	8.278
1977	152.659	265.562	314.201	162.893	793.695	72.700	8.455
1978	161.105	267.168	318.232	175.424	826.592	77.320	8.744
1979	170.089	269.544	323.026	188.206	862.502	81.137	9.06
1980	179.274	272.057	327.853	201.519	899.601	85.653	9.401
1981	184.691	268.873	325.65	210.953	918.458	90.209	9.543
1982	191.492	267.842	325.900	222.279	944.887	94.634	9.762
1983	197.255	265.429	324.331	232.717	966.786	99.015	9.932
1984	201.443	263.160	322.798	243.49	989.416	103.342	10.108
1985	209.159	261.340	321.702	254.95	1014.034	107.644	10.305
1986	215.925	260.323	321.497	267.539	1042.251	111.939	10.537
1987	214.927	259.578	321.544	280.62	1072.18	116.222	10.785
1988	230.048	258.770	321.441	294.50	1102.549	120.657	11.036
1989	236.683	257.381	320.584	307.97	1131.078	125.039	11.268
1990	242.118	254.663	317.92	320.204	1154.15	129.307	11.445

Note: 1 km = 0.6 mile.

f_k^r and f_k^u = fatality rate on rural and urban highways, respectively, in year k; and
f_0^r and f_0^u = fatality rate on rural and urban highways, respectively, in year 0.

The M_i^j-values can be taken from Table 1, and the f_i^j-values can be determined by using Equation 5. It was assumed that rural highway kilometers will be approximately constant over the period of interest, so that rural d will increase in the same proportion as rural vehicle kilometers.

The relative change in fatal risk over approximately two decades is summarized below.

Year	Relative Fatal Risk	Year	Relative Fatal Risk
1974	1.000	1983	0.960
1975	0.996	1984	0.956
1976	0.991	1985	0.952
1977	0.987	1986	0.948
1978	0.982	1987	0.944
1979	0.976	1988	0.940
1980	0.971	1989	0.935
1981	0.967	1990	0.933
1982	0.964		

There is a decrease of 7 percent, due simply to the changing urban-rural mix and the growing rural traffic density.

CASE 3: CHANGES OF MODE OR WITHIN-MODE CHARACTERISTICS

Two subcases are worthy of special note: the increased flight distances of airlines and the changing vehicle mix on highways.

Commercial Flight Distances

The failure index for nonstop flights by commercial air carriers can be determined by using Equation 2a

$$FI = (0.80 + 0.34 \text{ distance}) \times 10^{-6} \quad (2a)$$

where distance is measured in units of 15 000 km (24 000 miles). The constant 0.80 increases by 0.80 for each additional stop, because of the increased risk associated with landings and takeoffs.

Consider an airline that has an increasing average distance and a constant passenger volume: The FI will increase, but by much less than the passenger kilometers of travel. Thus, such conventional statistics as fatalities per million passenger (or vehicle) kilometers will decrease; indeed, they will change almost directly inversely to average distance. Nonetheless, the true safety of any individual trip of a given distance (as properly measured by the A- and B-values) will not have changed at all.

It should be noted that this case relates to an apparent change in the underlying safety of the mode and is induced by the use of a limited measure (e.g., fatalities per million passenger kilometers). The cases above related to actual changes that would take place, the true causes of which might be overlooked. Both types, however, illustrate the possibility that some extraneous and irrelevant measure might accidently claim credit—real or imagined—for changes that are observed in a simple before-and-after study.

Changing Vehicle Mix

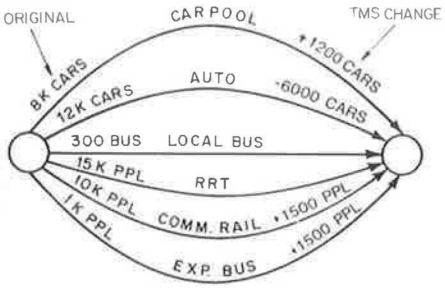
The current mix of heavy versus light vehicles is changing; the percentage of the light vehicles is increasing. The need for fuel efficiency is the most important reason for this change.

A change in the accident effect can be described in terms of the simple probability that two automobiles in a collision will be of significantly different weights. In the special case of a head-on collision at equal vehicle speeds, for example, the collision between two equally heavy vehicles would tend to result in equal severity of damage. If either vehicle were much lighter, it would suffer the greater severity of damage because it would be pushed backward. The heavier vehicle would have a lesser severity simply because it would not be forced to zero speed.

For this case, the total severity of damage could actually be maximized when the fleet is a 50:50 mixture of heavy and light vehicles. Thus, the accident history could worsen and then improve simply based on random conflicts, as the vehicle mix moves toward a preponderance of small vehicles. Preliminary (and somewhat crude) calculations show a possible increase of 5-10 percent, followed by a comparable decrease.

It is interesting that, if the problem is actually experienced (i.e., by an increase in severity), it would be logical for the appropriate authorities to attempt to solve it. However, even an unsuccessful solution would appear to be successful if the percentage of small automobiles significantly passed 50 percent simultaneous with the implementation of the solution.

Figure 4. Hypothesized distribution of trips.



CASE 4: EFFECTS OF A TRANSPORTATION SYSTEM MANAGEMENT ACTION

Because there is such a diversity of possible actions that can be taken in a transportation system management (TSM) effort, only a simple illustration is addressed here.

Consider the situation illustrated in Figure 4 and based on a hypothesized distribution of trips by several modes in the corridor of interest. The FI values for the subject modes can be used to compute a person-weighted total risk, defined as the summation over the modes of "people times the individual modal FI values", computed for the initial system.

Based on the forces that motivated the TSM action (e.g., increased utilization of capacity or energy conservation), it is hypothesized that the amounts shown on the right-hand side are put into effect. The total person-kilometers is not changed, but the total system risk has had a net decrease of 8.6 percent. This simply highlights the fact that a shift among modes, whether due to TSM actions or other causes, can itself induce changes in the total societal baseline. At the same time, the individual modal FI values for the individual traveler may not change.

CONCLUSIONS

In any systematic study, it is necessary to evaluate the effectiveness of any countermeasures taken. This is often done by a simple before-and-after study of relevant statistics. Unfortunately, many safety-related studies involve long time periods in the collection phases. This can be much more than an inconvenience. As illustrated in this paper, it is quite reasonable that major forces and trends in our society (or in any society) will cause the safety baseline to change during the analysis period. Without careful planning, historical data can be rendered meaningless and erroneous conclusions can easily be drawn. This paper illustrates some key forces that will cause future changes in the accident experience large enough to rival or exceed the effects of most rather successful accident countermeasures and make some rather meaningless ones look rather good.

ACKNOWLEDGMENT

This paper is based on a dissertation submitted by J. Byun to the Department of Transportation Planning and Engineering, Polytechnic Institute of New York, in partial fulfillment of the requirements for the Ph. D. degree. The work was conducted in the Transportation Training and Research Center, Polytechnic Institute of New York, as an element of the University Research Program, U.S. Department of Transportation. This paper was prepared under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. government assumes no liability for its contents or the use thereof.

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Publication of this paper sponsored by Committee on Transportation System Safety.

**J. Byun was with the Transportation Training and Research Center, Polytechnic Institute of New York at the time this research was performed.*

Applicability of Behavior Theory to Transportation

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The applicability of two theories of behavior—the humanistic theory and the behavioristic theory—to two areas of transportation—safety and modal choice—was tested. The first experiment supported the use of the behavioristic theory to explain driver compliance to speed limits and found that public information campaigns were ineffective. The second experiment also supported the use of the behavioristic theory and showed that reinforced choices will be made more often in an environment where positive controls govern the consumers' modal choice.

At least since 1970, the federal and state governments have attempted to coordinate their concerns with transportation environmental safety, pollution, and energy conservation. Throughout the same period, and especially since the 1973-1974 energy crisis, the federal government has attempted to reduce the use of petroleum-based fuels. As a re-