ERRATIC MANEUVERS AS AN INTERCHANGE-DESIGN FEEDBACK TOOL

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Establishing basic design, safety, and aesthetic standards and criteria for interchanges does not guarantee that there will be no problems. The designer still faces a high degree of uncertainty regarding the actual operating characteristics of each completed facility. Iterative design adds a degree of dynamism to a basically static process. An initial design is developed, evaluation criteria are applied, and through feedback, the design is modified. The design feedback loop may consist of profile models, 3-dimensional models, computer graphics, experimental building, and driver-behavior analysis. Driver behavior on an existing facility can be observed to see whether it conforms to the behavior that was presumed in establishing design criteria. Deviation from assumed behavior then is evaluated for severity, magnitude, frequency, and the expected trend over time. Furnished with a knowledge of the degree of erratic and hazardous driving, the engineer then is faced with translating these data into alternative solutions. The research discussed herein concerns the operating characteristics of a freeway-to-freeway interchange in Council Bluffs, Iowa. A driver-behavior analysis was conducted by using videotape records of operations, and alternative solutions were presented.

•INTERCHANGES exist on 2 levels. They integrate the small, physical elements of the roadway, and they are part of a large-scale system that integrates interchanges and other route-network components. Physical, economic, and ecological constraints are involved with both levels of interchanges.

The basic guides to interchange design traditionally have identified the interchange as a collected set of elements such as acceleration-deceleration lanes, turning roadways, and the like (1, 2). Design criteria are contained in the basic guides (1, 2), safety guides (3), and other environmental or safety standards. These criteria are based on data from vehicle operating characteristics, driver behavior, and roadway characteristics. One analysis of the highway design process concluded that the intermingling of design criteria and design elements in the design guides resulted in a "negative" process in which the designer had to be content with avoiding operation failure of the constructed design (4).

Roadway systems criteria, which aid in integrating the interchange into a continuous route path, include highway capacity and level of service (5), lane balance (6), driver expectation (7), engineering systems analyses (8), and state-of-the-art surveys (9). Because conceptualizing the integrated effect of all these factors is difficult, considering provision for design feedback is useful and desirable. This feedback becomes a means of identifying and evaluating modifications to the initial design.

Five basic techniques have been identified that can introduce feedback into the interchange design process: profile models, 3-dimensional scale models, computer graphics, "experimental building," and driver-behavior analysis (11, 12, 13, 14, 15, 16, 17, 18, 19). This paper deals with an attempt to use erratic vehicle maneuvers as a measure

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of driver-roadway interaction to evaluate an existing freeway-to-freeway interchange and to evaluate possible alternative solutions to operational problems associated with the roadway.

ERRATIC MANEUVERS

Interest in the erratic nature of traffic movements under certain conditions developed to a large extent through research seeking to optimize freeway interchange signing and driver communication (20). Logic dictated that rational drivers do not choose to execute hazardous and erratic maneuvers. Therefore, the driving task required to negotiate the roadway must have been misunderstood or miscommunicated. Motorist complaints of having missed exits or having turned onto the wrong exit roadway at cloverleaf interchanges have led to attempts to better communicate the interchange configuration by diagrammatic signs. According to information presented at the April 1973 Iowa State Highway Commission Human Factors Symposium, observation of traffic flow approaching cloverleaf interchanges indicates that erratic maneuvers of drivers who cross gore areas and make improper lane changes are not reduced significantly by use of diagrammatic signs, which leads one to conclude that such signing is relatively ineffective.

Human factors engineering has dwelled on many of the physiological and psychological effects of traffic stream flow on erratic driver behavior. Research has sought to identify where drivers look; how drivers judge speed and distance; what combinations of traffic speed, volume, and density create driver tensions; and what factors modify normal driving behavior. Typically, the traffic engineer and the highway designer consider driver limitations as uncontrollable constraints on the development of an optimum transportation system. Introduction of human factors concepts into the planning, design, and analysis of highway systems encourages the engineer to seek a causal relationship between erratic maneuvers executed by the driver and the various characteristics of driver-vehicle-roadway interaction.

Observing erratic maneuvers within a roadway section does not guarantee immediate positive feedback of information to the designer. Analysis of traffic behavior must provide an insight into the conditions of traffic flow and roadway design that contribute to erratic maneuvers, provide an objective quantified estimate of the hazard associated with the current condition, and yield an estimate of probable future conditions. A rudimentary basis then exists for generating and evaluating potential corrections to the undesirable traffic condition.

IOWA CASE STUDY AND EXAMPLE

Agency Concern

The Iowa Department of Transportation had received complaints from motorists that, when they negotiated the interchange of I-29 and I-80 in southwest Council Bluffs, Iowa, erratic maneuvers by other drivers had forced them into dangerous situations. Staff review of the design and operation of the facility generated several alternative solutions. However, in an effort to obtain a comprehensive analysis of the problem and consider a broad spectrum of possible solutions, the department contracted with the Engineering Research Institute at Iowa State University to conduct a study of certain sections of the interchange area. Preliminary on-site investigation indicated that analysis of erratic maneuvers from data collected with videotape techniques would be the appropriate procedure.

Data Collection

Figure 1 shows the specific areas studied within the interchange. One problem site was identified as the area of the I-29 South and I-80 East divergence (site 1). The divergence occurs on a sharp curve to the right. Immediately upstream of the divergence area, Iowa-192 interchanges with I-29 and I-80 in a partial cloverleaf. A major truck stop and truck terminal area adjacent to this interchange result in a large volume of low-speed truck traffic in the right lane approaching the divergence area. A significant number of these trucks exit left onto I-80 East and weave across 3 freeway lanes in about 500 linear ft (152.4 m) of freeway section. Out-of-state drivers in the traffic stream and other drivers unfamiliar with the route cause frequent near-misses.

Videotape records of the traffic operations were obtained from a vantage point on a bridge overpass. Figure 2 shows the curving geometry and traffic moving through site 1. To delineate the area and identify the movement of each vehicle through the problem area, we established reference sections, as shown in Figure 3. Reference section A-A was marked with temporary pavement striping tape on the paved shoulders just upstream of an added third lane. Reference section B-B was at an overhead sign bridge. Reference section C-C was delineated by luminaire standards and striping tape on the shoulders.

All possible maneuvers of vehicles negotiating the area between reference sections A-A and C-C were classified according to lane placement at each section as shown by the data given in Table 1. Normal (desirable) maneuvers occurred when vehicles in the left lane at A-A exited left and vehicles in the right lane at A-A exited right. Any other maneuver was considered erratic. The erratic category was subdivided into undesirable and hazardous maneuvers. Vehicles moving laterally more than 1 lane between reference sections [each section is less than 500 ft (152.4 m) long] to change lanes and vehicles using the third lane as a passing lane between sections A-A and B-B to exit right were considered to be making hazardous maneuvers.

Site 2 was near the I-80 West and I-29 North merge area. Through the interchange, I-80 West narrows from 2 lanes to 1 on a curve to the right with a left lane drop becoming a right entrance ramp onto I-29 North. A portion of the I-80 West roadway is on a structure so that railings and other features limit the driver view. A camera was mounted on a 30-ft (9.1-m) luminaire standard beyond the merge area so that the field of view included both the lane drop on the ramp and the painted channelization in the merge area. Figure 4 shows the configuration of the site.

Figure 5 shows the delineation of site 2 for data analysis. Reference section A-A was marked by existing 48-in. (121.9-cm) signs on both sides of the road at the beginning of the painted channelization designating the ramp lane drop. Reference section B-B was located at the beginning of the barrier-curbed edge of the ramp lane drop and marked with temporary striping tape marks. Reference section C-C was marked by striping tape on the shoulders at the physical nose; reference section D-D was marked similarly at the end of the painted nose.

All maneuvers were classified according to the list given in Table 2. Vehicles staying in lane 2 all the way through were considered normal. Vehicles staying in lane 2 until past the physical nose of the ramp and then sharply crossing the painted channelization to enter the right lane of I-29 North were noted as making undesirable maneuvers if no I-29 North traffic was in the merge area. Similarly, vehicles entering the site in the left lane of I-80 West (ignoring the advance warning of a lane drop) but otherwise executing a maneuver as previously described were considered to be making undesirable maneuvers. Also any vehicles entering the site at reference section A-A in the left lane of the I-80 West ramp but, from that point, maintaining a position in lane 2 were considered to be making undesirable maneuvers. All other maneuvers were considered hazardous.

The Iowa Department of Transportation conducted a recording count 24 h/day for 7 days on all approaches into each site and exit legs of each site. We selected from these data 18 half-hour periods to record the traffic operations at each site in an attempt to cover the maximum variation in traffic conditions with a minimum amount of field data.

Figure 1. Interchange study sites and accident history through July 1973.

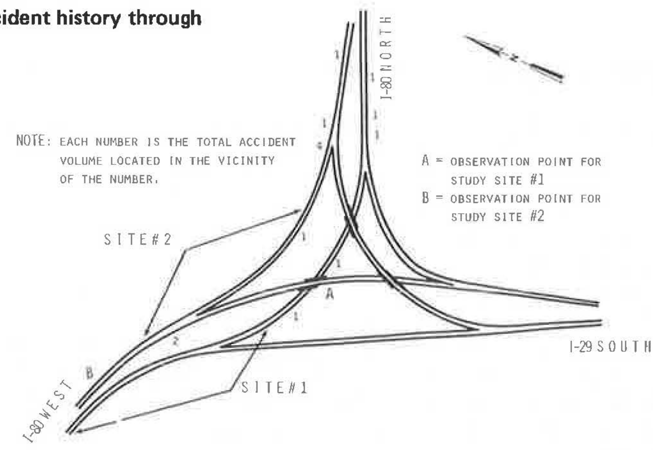


Figure 2. View of traffic at site 1 from the observation point.

Figure 3. Lane designation and identification sections for study site 1.

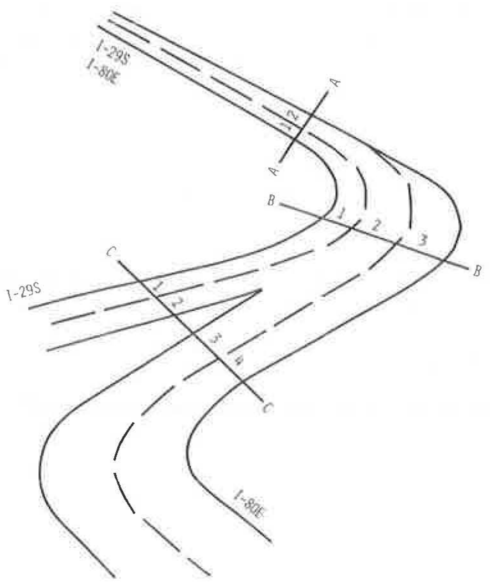


Table 1. Maneuver designations at site 1.

	Erratic	
Normal	Undesirable	Hazardous
111, 112, 223, 224, 234	121, 122, 123, 124, 134, 211, 212, 221, 222, 233	113,[a] 114, 131, 132, 133, 213, 214, 231, 232

[a]Vehicle that is in lane 1 at section A-A, lane 2 at section B-B, and lane 3 at section C-C (as shown in Figure 3).

Figure 4. Traffic moving through site 2 under camera mounted on luminaire standard.

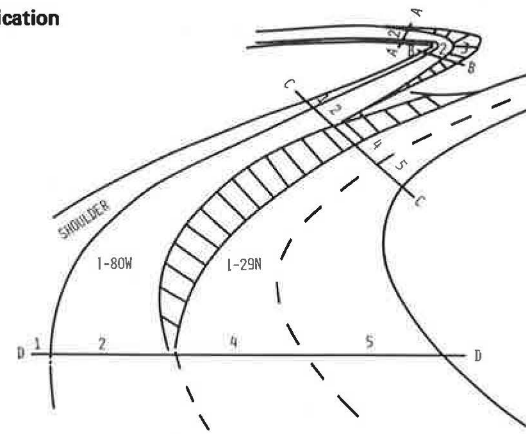


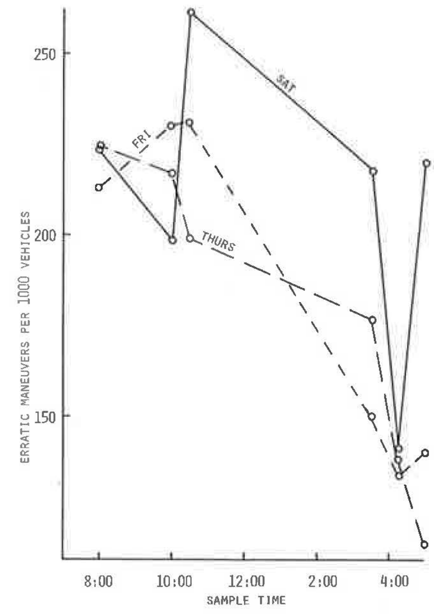
Figure 5. Lane designation and identification sections for study site 2.

Table 2. Maneuver designations at site 2.

	Erratic	
Normal	Undesirable	Hazardous
2222-any	2224-00,[a] 3224-00, 3222-any	2225-any,[b] 2322-any, 3322-any, 2324-any, 2325-any, 3225-any, 3324-any, 3325-any, 3224-any,[c] 2224-any[d]

[a]Vehicle that is in lane 2 at section A-A and continues in lane 2 through sections B-B and C-C but changes to lane 4 in exiting the area at section D-D with no I-29 North traffic in lane 4 or 5 as the vehicle reaches the merge area.
[b]An I-29 North vehicle is in either lane 4 or lane 5 as the I-80 West vehicle negotiates the merge area.
[c]Exclude maneuver 3224-00.
[d]Exclude maneuver 2224-00.

Figure 6. Erratic maneuvers at site 1.



Data Analysis

Data tapes were brought back to a central laboratory after all data were collected. There a technician replayed each tape on a playback unit with stop-action capacity. Each vehicle on the tape was identified by type of vehicle and lane placement at each reference section according to the classification of movements given in Tables 1 and 2. Summaries of these reduced data are shown in Figures 6 through 9. The rate of occurrence of erratic maneuvers at site 1 (Figure 6) was quite consistent for all 3 days at each sample period, and chi-square tests indicated no significant differences. The rate of occurrence of hazardous maneuvers as a part of the erratic maneuvers at site 1 (Figure 7) also had no significant variation. This is in direct contrast to the traffic characteristics of the samples at site 2. In the merge area, the rate of erratic maneuvers and the rate of occurrence of hazardous maneuvers were significantly different among the sample days. Changing traffic composition within the traffic stream is evidently more of an influence on traffic operations in merge situations than in divergence situations.

At site 1 (Figure 7) during the morning peak period, the rate of hazardous maneuvers approaches the currently accepted critical level of 3 percent. Accident record report forms available at the Iowa Department of Transportation for accidents recorded through July 1, 1973, were examined. Those individual reports that documented the accident in sufficient detail to determine that the accident definitely occurred within the study interchange are noted on Figure 1. Only 1 accident could be identified positively near site 1. This supports the traffic movement analysis that found that the rate of hazardous movement occurrence usually is low enough that the probability of collision is low.

This discussion of the current hazard at site 1 is somewhat misleading. Even though the hazardous maneuvers currently are a relatively small percentage of the flow, the percentage of the traffic entering the merge area in lane 1 (the outside lane) and exiting to the left onto I-80 East is considerably higher as shown by the data given in Table 3. Not all of these movements are hazardous now because of relatively low total volumes. These data provide a key to estimating the future level of hazardous maneuvers that ultimately may approach 5 to 8 percent of the total traffic as traffic increases to design volumes.

At site 2 (Figure 8), the rate of hazardous maneuvers significantly exceeded the currently accepted critical level of 3 percent of total volume. Figure 1 shows that 3 accidents that appear to be related to the traffic conflicts associated with erratic maneuvers at site 2 have been recorded in the vicinity of the lane drop and merge area.

The information given in Table 4 indicates the percentage of traffic using the I-80 West ramp of the interchange that traveled on the painted channelization in the lane drop area and crossed the painted channelization in the merge area in conflict with I-29 North vehicles. Some of these percentages, especially those for weekend travel, are quite high. As traffic volumes increase, these percentages can be expected to increase. Furthermore, because many I-80 West vehicles crossed the merge area painted channelization but did not do so when I-29 North traffic was in the merge area, increases in I-29 North traffic are anticipated to increase conflicts and hazards. Consequently, the hazard can be expected to worsen rather than be alleviated over time even though the current hazard is serious but not hypercritical.

These observed variations formed the basis of an apparent trend in characteristic behavior contributing to the hazard and potential hazard at each site. At the route divergence area (site 1), the problem is improper lane placement. At the merge area (site 2), the problem is associated with vehicles driving over painted channelization in their chosen paths at several locations. Isolating these movements as the percentage of approach flow traffic to each area yields the trends shown in Figure 10. These trends can be a basis to hypothesize the possible effect of alternative improvements on traffic operations.

Figure 7. Hazardous maneuvers at site 1.

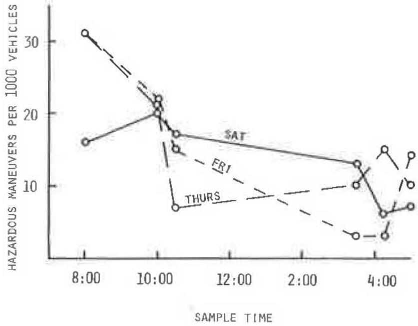


Figure 8. Erratic maneuvers at site 2.

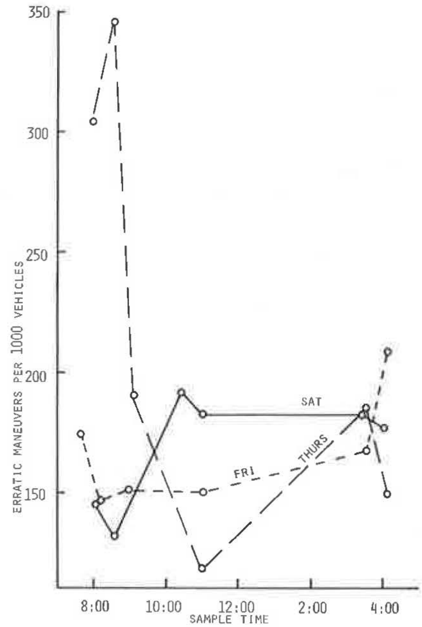


Figure 9. Hazardous maneuvers at site 2.

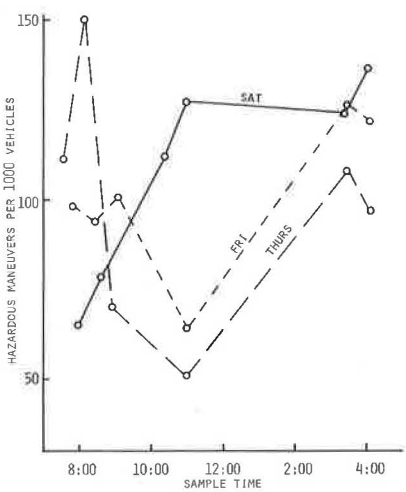


Figure 10. Relation of traffic volume to conflict.

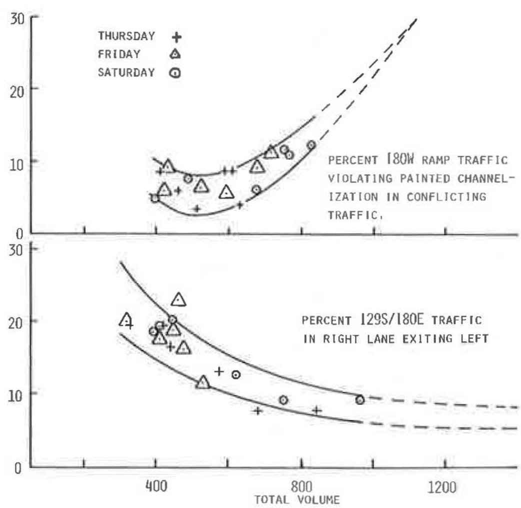


Table 3. Percentage of total traffic entering in lane 1 and exiting I-80 East.

Survey Date	Tape 1	Tape 2	Tape 3	Tape 4	Tape 5	Tape 6	Total
July 26, 1973	19.6	19.6	16.5	13.2	7.9	7.7	12.6
July 27, 1973	18.7	19.5	20.3	12.6	9.3	9.2	13.5
July 28, 1973	20.0	17.6	23.3	16.4	11.8	19.1	17.8

Table 4. Percentage of total traffic in conflict on the I-80 West ramp traveling on the painted channelization in the left lane and merge area.

Survey Date	Tape 1	Tape 2	Tape 3	Tape 4	Tape 5	Tape 6	Total
August 2, 1973	4.1	8.6	6.0	3.5	8.7	8.7	6.6
August 3, 1973	6.4	6.1	9.2	5.7	9.1	11.4	8.2
August 4, 1973	5.0	7.7	11.7	10.9	6.2	12.3	9.6

Interpretations

At the divergence area of I-29 South and I-80 East, the data show that the percentage of traffic executing hazardous weaves to exit is reduced as the total hourly volume approaching the area increases. An extrapolation of the trend band encompassing the central tendency of the data (Figure 10) indicates that the percentage of traffic making a hazardous exit will stabilize at around 5 to 8 percent as approach volume continues to increase. Increasing traffic density with this magnitude of conflict would make this an area with a high accident potential.

As traffic volumes increase approaching the divergence of I-29 South and I-80 East, the level of service can be expected to drop rapidly. Vehicles in the right lane desiring to exit on the left can be considered functionally to be weaving. Because the length of section over which such a maneuver may take place is relatively short [500 to 800 ft (152.4 to 243.8 m)], each vehicle executing such a maneuver can be expected to have an effect on level of service equal to about 3 straight-through vehicles (5).

Increasing traffic volumes will not alter the character of the traffic conflicts associated with the merge area of I-80 West and I-29 North. As traffic increases on the I-80 West ramp and, to a lesser known degree, as I-29 North traffic increases, the absolute and relative number of conflicts can be expected to increase. However, these will be "more of the same." Consequently, that which will improve traffic operations in this location now will lessen future hazards simultaneously.

Alternative Solutions

Observation of the data tapes for qualitative evaluation of the traffic conflicts and review of the data analysis results for quantitative measure of erratic maneuvers generated possible alternative approaches to solving the operations problem at each site.

Site 1

Five alternative solutions were generated for site 1.

1. Develop an exclusive truck lane to provide the truck traffic entering the freeway at Iowa-192 a separate, directional grade-separated ramp to I-80 East.
2. Close the loop entrance ramp from Iowa-192 to I-29 South and I-80 East either during hours of excessive hazard or permanently.
3. Designate the left lane in the area approaching the interchange complex to be for I-80 East traffic only and designate the right lane to be for I-29 South traffic only.
4. Add a third traffic lane between the Iowa-192 entrance and the divergence area of I-80 and I-29. Resurfacing and restriping the lanes would yield a split lane configuration throughout the area of 2 to 3 or 2 to 2.
5. Replace the conventional arrow and legend signing with diagrammatic interchange signing.

Based on erratic maneuvers, the fundamental problem is due partially to improper lane placement of through traffic vehicles and partially to slow-moving trucks entering the roadway. Solution 3 has the greatest potential to improve through-vehicle lane placement with the minimum cost. Solutions 4 and 5 might have almost no effect on existing operations.

Site 2

Four alternative solutions were generated for site 2.

1. Install larger signs warning of a lane drop on the turning roadway and perhaps

install flashers on the advance warning signs to attract more attention from the driver.

2. Rumble-strip the existing painted channelization for more positive delineation of the designed vehicle paths.

3. Add a lane to the turning roadway to provide a full 2-lane ramp connection. The added lane can be dropped in the ramp taper area.

4. Change the turning roadway from a left-lane drop to a right-lane drop.

The erratic maneuvers are associated with drivers who do not expect the left lane to be dropped on a 2-lane Interstate route and with drivers who intentionally use painted channelization to execute hazardous passing maneuvers. A combination of solutions 2 and 4 offers the best potential to provide proper traffic operation consistent with the basic design. Solutions 1 and 3 have limited potential to modify the basic existing operation.

FINDINGS

Videotape recording of actual traffic operation provided documented information about the traffic condition that generated motorist complaints. Erratic maneuvers can be quantified from the videotape data to provide a concrete measure of the degree to which drivers are actually using a facility as it was designed and constructed to be used. Hypothesized alternatives can be compared, at least on the basis of engineering judgment, for potential effect on reducing erratic maneuvers. In this manner, transportation professionals in operations, design, and planning have a common measure for communicating the value of their proposed changes to an existing design. On the basis of this case study, we recommend that erratic maneuvers be examined to provide feedback from the operations to the design of interchanges.

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