ENGINEERING ANALYSIS CLOSING REPORT

SUBJECT: Alleged Loss of Power Steering Assist in 1992-1993 Ford Crown Victoria Police Vehicles

EA No.: EA94-022 Date Opened: 30-JUN-94 Date Closed: MAR -2 1995

BASIS:

Preliminary Evaluation, PE94-032, was opened on April 8, 1994, following receipt of information submitted to the National Highway Traffic Safety Administration (NHTSA) by the Bergen County, New Jersey, Prosecutor's Office (BCPO). The information described the fatal, single-vehicle accident of a Paramus, New Jersey, police officer which occurred on November 22, 1993. The report included a number of documents regarding the BCPO's investigation of that incident.

According to the information provided to NHTSA, Police Sergeant Vincent Brock was fatally injured while responding to an emergency call, when his 1992 model year Ford Crown Victoria police patrol car failed to successfully negotiate a series of lane-change maneuvers, and the vehicle impacted a light standard at the left-side B-pillar. The Bergen County Prosecutor's investigation of that incident included a series of vehicle tests, an engineering examination of certain evidence regarding the Brock incident, and inputs from the Paterson, New Jersey, Police Academy's chief driving instructor with potentially relevant knowledge of the steering system performance in the subject vehicles under certain unique maneuvering conditions.

Of particular interest to this agency was a report prepared by the American Standards Testing Bureau (ASTB) for the Bergen County Prosecutor. The ASTB conducted an engineering examination of the Brock incident and submitted a report which concluded the following:

> "In summary, our analysis of 1992 Ford Crown Victoria vehicles equipped for police use disclosed that the power steering assist function becomes impaired under extreme, but foreseeable conditions. More specifically, the steering wheel becomes difficult to turn when executing a series of quick turns or swerves with the operator's foot off the accelerator pedal. This condition can occur at relatively low speeds and becomes more pronounced at higher speeds and/or when braking during the maneuvers."

The ASTB report was submitted to this agency as an attachment to a letter dated April 4, 1994, by a Senior Investigator from the Fatal Accident Investigation Unit of the BCPO.

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The above letter also included as an attachment, a memorandum to all Bergen County Police Chiefs, which stated that the subject vehicle has a deficiency described as "power steering bind" or "deep throttle oversteer." Also submitted was a copy of an article that reportedly appeared in the December 1991 issue of Police-The Law Officer's Magazine and that described a "drop-throttle oversteer" condition, which tests had shown the 1992 police Crown Victoria to exhibit.

The above information delineates the specifics of the basis for initiating PE94-032. Information subsequently developed, including preliminary tests conducted by this agency, provided a basis for upgrading the referenced PE to the subject Engineering Analysis (EA) on June 30, 1994.

THE ALLEGED DEFECT:

The alleged defect in this investigation refers to unforewarned and significantly diminished level of steering power assist, including but not limited to, circumstances in which the power steering assist system may appear to have failed completely. In this regard, the safety-related issues include consideration of the vehicle operator's expectations of a level of power steering assist, and the possibility that the operator may perceive failure of the steering assist function if the amount of force required to steer the vehicle suddenly increases.

Most contemporary steering power assist systems are designed to reduce the level of power assist as vehicle speed increases. The "diminished" level of steering power assist of concern in this investigation, however, far exceeds that normally experienced as a result of the "variable assist" function. Of concern in this investigation is a significantly reduced level of power steering assist to the point of potentially giving the driver a signal that the steering system is binding or possibly locked, and that increasing the amount of input force on the steering wheel will have minimal effect, if any, on retaining directional control of the vehicle.

DESCRIPTION OF COMPONENT OR VEHICLE SYSTEM:

The subject vehicles in this investigation are four-door sedans equipped with 4.6 liter, electronic fuel injected engines and automatic transmissions. They are also equipped with a heavy-duty suspension package, and P225/70R15 radial tires. An antilock braking system is optional equipment on these vehicles.

The power steering assist system installed in the 1992-1993 Crown Victoria police vehicles utilizes the same design and components as that installed in the consumer version of the vehicle. It does, however, include a power steering fluid cooler and a steering gear

with a higher effort torsion bar. The basic system is depicted in the block diagram of Figure 3-A and includes components manufactured by several suppliers. The model CIII pump and XR-50 recirculating ball power steering gear are manufactured by Ford, and both designs have been used in various vehicles manufactured by Ford for several years.

The CIII vane-type, power steering pump is mounted directly to the engine by four retaining bolts, and is powered by a serpentine accessory drive belt. The pump design is such that its output is sufficient to provide full power steering assist at minimum engine (idle) speed. Connected to the pump body is the electronically variable orifice (EVO) actuator assembly, a component of the variable power assist feature of the system.

The EVO system is designed to vary the flow of fluid from the power steering pump as a function of vehicle speed and rate of steering wheel rotation, providing a variable amount of power assist under different vehicle performance conditions. The system provides full power steering assist at low vehicle speed for light driver effort, e.g., during parking maneuvers, and minimum assist at high speeds to enhance the driver's "road feel" and directional stability. During evasive steering maneuvers when the values of its two control parameters (vehicle speed and rate of steering wheel rotation) exceed predetermined thresholds, the EVO system restores full power assist.

An optical sensor, mounted on the steering column, is used to establish the rate of steering wheel rotation. When the steering wheel rotation rate reaches 30 rev per minute (rpm) i.e., 0.5 rev per second (rps), the output current to the actuator drops and additional power assist is provided. When the steering wheel rotation rate reaches 60 rpm (1.0 rps) and higher, the output current to the actuator reaches zero, and full power steering assist is provided.

The other EVO critical parameter is vehicle speed, measured by a sensor located on the transmission. When the vehicle speed is less than 10 miles per hour (mph) and the actuator output current is less than a specified amount, full power assist is provided. As vehicle speed increases to 25 mph, the output current increases linearly to another specified value. Beyond that speed, the output current increases linearly up to a third value and remains constant for all vehicle speeds greater than 88 mph.

The EVO actuator generates a differential pressure, dependent on fluid flow and current input. The differential pressure controls the position of the spool valve in the CIII pump. The actuator/spool valve regulates the flow of power steering fluid and when combined with a current controlling device provides the variable assist capability of the power steering system.

The outputs of the vehicle speed sensor and the steering wheel rotation sensor are analyzed continuously by a microprocessor in the EVO control module. With this information, the control module/microprocessor controls the EVO actuator valve, thereby

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regulating the fluid flow from the power steering pump. At low vehicle speeds, the actuator valve is controlled to provide full pump flow for full power assist. At higher vehicle speeds, the actuator valve reduces pump flow for reduced power assist. In evasive maneuvering, the actuator valve increases pump flow, and provides full power assist. A graphical illustration of the EVO output versus vehicle speed is shown in Figure 1, and Figure 2 shows a plot of "normal" steering effort versus vehicle speed.

The power steering unit is a torsion bar type of hydraulically assisted system, which provides power to reduce the amount of driver effort on the steering wheel for turning (Block Diagram of system shown in Figure 3-A). The steering gear assembly is attached to, and is an integral part of, the steering linkage as shown in Figure 3-B. An exploded view of the steering gear is shown in Figure 3-C.

The power steering gear is designed with a rack piston, worm and sector shaft in one housing, and a rotary valve sleeve assembly in an attached housing. Thus, all external fluid lines and hoses are eliminated as internal fluid passages are utilized between the rotary valve sleeve and the power cylinder. The only external fluid lines are the pressure and return hoses between the pump and the steering gear assembly.

The double-acting power cylinder piston is part of the gear housing. Fluid pressure may be applied to either side of the piston. The steering gear ratio is 14:1, and the gear requires 3.3 turns from steering stop to steering stop.

When power assist is not required, i.e., in a neutral, straight ahead position, the valve input shaft and sleeve are held in a central position by the torsion bar. Fluid flows from the inlet port through the outlet port and back to the pump. In this position, no area of the steering gear is under high pressure.

The valve input shaft is attached to the steering column/steering wheel on one end. The other end connects to the worm through the torsion bar, and provides the link to the wheel side of the steering system. When a steering maneuver is initiated, the rotational force applied by the driver through the steering wheel is transmitted to the worm where it meets the resisting force of the road wheels. When the steering forces are great enough, the rotational deflection of the torsion bar changes the relative position of the input shaft and control sleeve, directing the high pressure fluid to the appropriate side of the piston in the gear housing. This pressure differential on opposite ends of the piston helps to move the sector shaft, thus providing assist to the driver's turning effort. Fluid in the opposite end of the gear housing flows through the return outlet of the control valve and back to the reservoir/pump. As steering input effort is increased, the increased displacement of the valve provides a proportionately higher level of assisting pressure.

CORRESPONDENCE:

The primary request for information from the manufacturer was sent under PE94-032, by letter dated April 20, 1994. Ford responded to that inquiry by letter dated June 3, 1994, with a supplementary response dated June 13, 1994.

By letter dated September 26, 1994, Ford provided to NHTSA the results and discussions of additional steering/handling tests conducted in reference to the subject investigation. In addition, Ford submitted a letter dated November 17, 1994, in response to a verbal NHTSA request for a comparison of the accident experience of the subject vehicles with that of the Chevrolet Caprice.

An additional NHTSA request for information was sent by letter dated November 17, 1994. Ford responded to that inquiry by letter dated December 21,1994. All of the aforementioned correspondence has been placed in the public file.

PROBLEM EXPERIENCE:

The alleged defect in this investigation concerns an issue of performance; the ability of the power steering assist system to meet the vehicle operator's expectation of that system's performance. Further, this investigation concerns the performance of that system in a select subset of a total vehicle population under extremely aggressive, though foreseeable, operating conditions.

Through tests and data analyses, this investigation developed a sufficient scientific understanding of the alleged defect so that simple reports of "power steering failure or malfunction" could be evaluated accurately. With this knowledge, all reports and/or inquiries regarding this issue were evaluated to determine whether the circumstances and details of the report identified an actual instance of the alleged defect being experienced in the field.

NHTSA's consumer database was searched and found to contain a total of eight complaints related to the power steering systems in 1992 and 1993 Ford Crown Victorias. Seven of the eight complainants were contacted via a telephone survey. None of these complaints were found to describe a performance anomaly consistent with the issues being considered in this investigation. A memorandum summarizing the results of this survey was prepared and placed in the public file.

BCPO contacted Ford and was provided information regarding 19 reports potentially relevant to the alleged defect. In addition, several law enforcement agencies contacted the BCPO directly and provided additional information regarding their experiences. BCPO provided to NHTSA a summary report regarding the results of its contacts, including information from law enforcement agencies. The nature of the individual reports was

varied and included several complaints of diminished power steering assist at engine idle or during braking, claims of power assist loss at high vehicle speeds, and other information extracted from the manufacturer's Corporate Quality Information System (CQIS) reports. Information from Ford's CQIS reports was also provided to NHTSA directly by the manufacturer in response to an information request as a routine part of this investigation. Review of the BCPO summary report disclosed no new or significant information regarding a documented report of the alleged defect not reported by other sources. The BCPO report was placed in the public file for this investigation.
In response to NHTSA's request for information during the PE phase of this investigation, Ford provided by letter dated June 13, 1994, a total of 17 potentially relevant complaints and/or field reports of the alleged steering condition in the subject police equipment package vehicles.

Ford also provided 21 additional complaints or other reports involving non-police vehicles potentially relevant to this investigation. Five of these involved vehicles at operating speeds greater than 15 mph, and 16 reports involved vehicles for which "... a vehicle speed was not stated or implied and could not be determined." These reports fit a descriptive pattern consistent with NHTSA's original description of the alleged defect, which referenced alleged loss or diminished power steering assist at low to moderate vehicle speeds, i.e., 15 to 30 mph.

Information subsequently developed during the investigation established two facts regarding the actual relevance of the above complaints, as follows:

1. Non-police vehicles are not affected by the alleged defect in steering system performance, because of their inability to retain tire traction up to the point of onset of the alleged defect, and

2. Vehicle tests disclosed that if the alleged defect were to be experienced at speeds above 40 to 45 mph, it would not represent the primary compromise to vehicle safety.

Based on the above, it was established that the non-police vehicle complaints were clearly not relevant to this investigation. It was further established that vehicle speed was important in evaluating the potential relevance of police vehicle complaints in this investigation.

Ford also reported two accidents claimed to be potentially relevant to this investigation. One of these was the fatal incident reported by the Bergen County, New Jersey, Prosecutor. NHTSA conducted a detailed reconstruction of that crash and it is discussed in this report. The second incident reportedly involved the non-injury crash of a police vehicle in Louisiana while being driven "... very aggressively through a devised pylon course." No additional information was sought regarding this incident because it occurred in a vehicle test environment as opposed to actual in-service application.

Review of the documentation provided by Ford to NHTSA disclosed no information providing clear indication of the alleged defect being reported during in-service use of the su . vehicles under circumstances known to precipitate its onset.

NHTSA has not identified any verified and documented cases in which the alleged defect occurred during in-service use of the subject vehicles.

VEHICLE POPULATION:

The following numbers of subject vehicles were reported by the manufacturer as sold in the United States:

	POLICE	CONSUMER	TOTALS
1992 Crown Victoria	26,557	110,392	136,949
1993 Crown Victoria	28,219	71,964	100,183
TOTALS	54,776	182,356	237,132

Vehicles within the "Police-Equipment Group" as identified above, include the following standard equipment modifications that relate to power steering, steering, and suspension systems:

Heavy duty front and rear springs
Heavy duty rear front and rear shock absorbers
Heavy duty stabilizer bar
Power steering fluid cooler
Power steering gear (higher effort torsion bar)
High performance/H-speed rated tires

The above modifications give the police equipment vehicle group superior cornering, and better recovery characteristics in the event of temporary loss of control, than the consumer version of the 1992 and 1993 Crown Victoria.

No information was received or discovered during the course of this investigation to suggest or indicate that the alleged defect may affect the 1992 and 1993 model years of Mercury Grand Marquis vehicles. However, because the power steering assist system in

this vehicle group is essentially identical to that installed in comparable year Crown Victoria vehicles, the following sales statistics for the Grand Marquis were requested by NHTSA and reported by Ford:

1992 Model Year	146,370
1993 Model Year	82,977
Total	229,347

The above data for the Grand Marquis include all vehicles sold to consumers and fleet purchasers.

WARRANTY:

Warranty claims, "goodwill," or other types of policy adjustments and repairs potentially relating to the alleged defect were requested from the manufacturer. These data, although provided, contained insufficient detail to be useful in evaluating the potential of the alleged diminished power steering assist condition as a safety-related issue. Computerized warranty data typically reflect only a basic description of an owner's concern and the repairs made by a dealer to address it.

The requested data contained 203 reports that cited the power steering pump or gear as a relevant component for a customer concern code of "hard to turn." This report explains, in later sections, why any such customer complaints resolved by repair or replacement of the power steering pump are clearly not relevant to this investigation. The data are tabulated by month of report, component, and relevant vehicle speed in the manufacturer's letter to NHTSA under PE94-032 dated June 13, 1994. It is also noted that these data include reports for consumer versions of the 1992-1993 Crown Victoria.

SERVICE BULLETINS:

No service literature or bulletins of any type are known to have been issued by Ford to its dealers or distributors regarding the alleged defect in the subject vehicles.

PARTS SALES:

Parts sales information was not requested in this investigation, based on test results during the PE phase which suggested that the alleged defect was a performance-related issue, rather than a failed part issue. Sales of replacement parts were judged not significant to this investigation.

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DESIGN, MATERIAL, AND/OR PRODUCTION MODIFICATIONS:

Ford responded to NHTSA's inquiry on this matter by stating that 1994 model year Crown Victoria police equipment group vehicles included one design change that could affect the performance of the power steering system under certain unique conditions of low engine speed. Some law enforcement agencies reported that during U-turns or sharp turning maneuvers at speeds of approximately 5 mph following hard braking, the subject vehicles could exhibit reduced power steering assist or high steering effort. Ford's analysis of this condition found that a momentary reduction in the engine idle speed to about 50 rpm less than specified idle speed could reduce the output of the power steering pump to less than that required for full steering assist. The condition was eliminated in the 1994 model year police equipment group Crown Victoria by revising the algorithm of the electronic engine control module to prevent this temporary reduction of engine idle speed below the specified value.

No substantive changes relating to the alleged defect were identified in the design or components of the power steering system installed in the subject vehicles.

A subsequent NHTSA inquiry to Ford dated November 17, 1994 posed questions regarding suspension modifications in Crown Victoria police vehicles produced since the 1993 model year. Ford responded to that inquiry by letter dated December 21, 1994, and identified six design changes to suspension system components incorporated into production since June 1993. According to Ford, the design changes cited would, individually or as a group, improve slightly the handling characteristics of a 1994 Crown Victoria police vehicle as compared to a 1992 model.

TESTING:

All test activities during this investigation were conducted at the NHTSA Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. The complete test report prepared by VRTC (VRTC-74-0331) in support of this investigation has been placed in the public file.

A comprehensive test program was initiated to address the potential safety related implications associated with the following two objectives:

1. To identify and quantify through a series of engineering tests of instrumented vehicles, the performance characteristics of the subject power steering system under driving circumstances sufficiently aggressive to exhibit the alleged "binding" or "lockup" of the system. In addition, to compare the performance of the subject power steering system with that of a peer vehicle, specifically the 1992 model year Chevrolet Caprice police cruiser.

2. To evaluate through a series of exercises with a cross-section of "typical" police officer volunteer drivers, the behavioral/driving responses of those officers to an unforewarned occurrence of the alleged defect.

The VRTC report provides full information regarding the preliminary aspects of the test program, including establishing a road course for the steering/handling evaluations, test vehicle identifications, initializing steering system static performance to manufacturer specifications, and instrumentation/data acquisition systems.

Also documented in the VRTC report are the road test courses used in this investigation, together with the basis for having selected these courses. The fundamental premise in selecting the test courses was to utilize widely-accepted, precision type, high-maneuverability test circuits. This type of course provides a good representation of the types of situations potentially presented in congested urban environments which, when driven in a very aggressive manner as might be anticipated during police/emergency responses, would be sufficient to evaluate the onset of the alleged defect. The test courses proved adequate in providing the required difficulty to both drivers and steering system, and all police officers who drove the test vehicles during subsequent phases of the test program agreed that the courses were successful in achieving those objectives. A typical test course is shown in Figure 4; it is based on the Cumulative Skills Pursuit Course C as recommended by the Task Force report of the International Association of Directors of Law Enforcement Standards and Training, dated May 1989.

The initial series of tests included a series of "drop throttle serpentine" tests, a series of quick turns of about one full rotation of the steering wheel, with the driver's foot removed from the throttle pedal. These tests were performed at speed of 35 mph, and repeated in the 5 mph increments up to a 55 mph maximum. The results of these tests are documented in the VRTC report and were first the quantified indicators of increased steering torque requirements under repeated steering reversals in the subject vehicles. Subsequently, other similar tests were conducted and described as lane change and slalom maneuvers. Results of these tests are summarized in this report and are provided in detail in the VRTC report.

VALIDATION AND QUANTIFICATION OF THE ALLEGED DEFECT:

It was established that a driver must negotiate the course with a maximum elapsed time of 29 seconds, while avoiding impact with all of the traffic cones defining the course. Drivers were instructed to consider that each cone represented a pedestrian, another vehicle, or a fixed object. These qualifying criteria were determined to require sufficiently aggressive driving to precipitate the onset of the alleged defect.

Results from the engineering test phase were analyzed, and the following significant determinations made:

1. The "normal" level of driver input torque for the 1992 Crown Victoria at low to moderate speeds was found typically to be on the order of 5 to 7 foot-pounds (ft-lbs).

2. When the limit of performance of the subject power steering system was approached, precipitated by rapid steering reversals as the test course was driven, the driver input torque requirement increased by a factor of approximately four, i.e., 20 to 28 ft-lbs.

3. In comparison, the typical, "normal" steering input effort required in the 1992 Chevrolet Caprice was on the order of 8 to 10 ft-lbs. The Caprice also demonstrated an ability to experience increased input torque requirements during the highly aggressive maneuvers in the test course, but the torque increase represented only a two-fold magnification of the normal level and had a shorter time duration than that exhibited by the Crown Victoria. Coupled with the overall "feel" of the Caprice as a "heavier" vehicle than the Crown Victoria, these factors allowed a driver perception that the Caprice did not exhibit steering system performance characteristics that should be considered "anomalous."

Typical data plots of steering wheel angle and torque versus time for the unmodified 1992 Crown Victoria (Vehicle 5) are shown in Figure 5; comparable data plots for the 1992 Caprice (Vehicle 3) are shown in Figure 6.

Analysis of the data acquired during the engineering tests of the subject vehicles provided indicators of the possible origin of the "performance anomaly" in the power steering system. A series of procedures to improve the power steering fluid flow in the steering gear was performed, the system reassembled, and tested to evaluate the performance of this "modified" system. The test data, as well as driver response, showed a marked improvement in the ability of the power steering system to respond to driver input while maneuvering the test course. In so doing, the system response was such that the "lag, binding or perception of system lock-up" was significantly reduced. At this phase of the test activities, the modified vehicle being used by the test drivers, described in the VRTC report as Drivers A, B, and C, was equipped with a steering gear reworked to eliminate the anomalous system performance.

BEHAVIORAL/DRIVER RESPONSE TESTS:

The second phase of the test program involved utilizing as test vehicles, the standard or unmodified Crown Victoria, a semi-modified Crown Victoria (with steering gear reworked to reduce but not completely eliminate the anomalous performance), and a Chevrolet Caprice. These test vehicles were driven over the prescribed test course by a group of police officer volunteers. Given no prior knowledge of the specific nature of the driving tests, the officers were advised only that the "handling characteristics" of the vehicles

were being evaluated. The results of this test series were documented by videotapes of pre- and post-driving interviews, as well as an inside car/over the shoulder view of the steering wheel during the test runs. The test vehicles were not instrumented for data acquisition.

The tests in this phase of the program were intended to provide a body of information from which to assess the behavioral driving responses of typical police officers when confronted with the unforewarned steering anomaly identified in the first phase of testing of the Crown Victoria.

The initial phase of the test program focused on validating and quantifying the alleged defect, but also enabled some additional judgments which became important in subsequent tests with volunteer drivers. Due to the driving circumstances necessary to precipitate the onset of the alleged defect, it was apparent that:

1. All police officers would not be likely to possess the upper body strength necessary to steer quickly enough to produce onset of the alleged defect.

2. All police officers would not be likely to possess the skills to drive the vehicle aggressively enough to create the onset of the alleged defect.

3. Some, but not all, police officers would probably have sufficiently good driving skills to minimize the onset of the alleged defect. In this regard, it was qualitatively established that the better, "smoother" driver would probably be able to negotiate the test course with less apparent lag or binding in the steering system.

4. By "learning" the test course through repeated driving exercises, most police officers could improve their driving performances, becoming "smoother" and probably achieving lower elapsed times.

Thirty-four active police officers, male and female, with various types of upper body physique and different capacities of strength, participated in this phase of the test program. In addition, these volunteers represented a spectrum of law enforcement experience in terms of years as well as type and size of agency, and possessed various amounts and types of driver training and experience. A total of 835 test course runs were completed by the police volunteers, and each individual run provided more than one "opportunity" for onset of the subject steering anomaly. As stated in the VRTC report, each test run typically created three events of so-called "supertorque"- driver torque input exceeding 7.5 ft-lbs and typically in the 15 to 30 ft-lbs range, when the operator has "beaten" the steering system hydraulics and the application of additional torque does not produce a corresponding level of turning response at the road wheels of the vehicle. These events normally occurred just prior to two U-turns and near the end of the test

course as the vehicle maneuvered through the successive lane changes.
The following is a tabular summary of the results of the test runs completed by the police volunteer drivers:

	Unmodified Crown Victoria (294 Tests)	Semi-Modified Crown Victoria (306 Tests)	Caprice (235 Tests)
TEST RESULTS			
Steering Wheel "Bind"	50	21	12
Steering Wheel "Lockup"	27	15	1
Steering Wheel "Kickback"	29	13	0
Driver Lost Control of Vehicle	3	0	0
Driver Failed to Stay in Lane	2*	0	0

* These 2 incidents are a subset of the 3 incidents in which driver lost control of vehicle.

The above tabulation of test results provides a numerical itemization of the numbers of specific occurrences during the tests with volunteer drivers. It is noted that, while the semi-modified steering gear in one of the Crown Victorias did not eliminate the difficulty associated with maneuvering successfully through the test course, the improvements did contribute to better driving performances than in the unmodified subject vehicle.

The significant occurrences, described as steering wheel binding, lockup, and kickback have meanings that relate to the input effort of the driver at the instant of experiencing the supertorque events. Tabulations of these occurrences were made by performing frame-by-frame analyses of the videotapes taken from the on-board camera (over driver's right

shoulder). In each type of occurrence, the driver experienced a steering anomaly to the point where the effort being applied to the steering wheel was in the supertorque range of 15 to 30 ft lbs. Upon crossing that threshold of steering input effort, each driver instantly continued torque application, and the amount of that additional effort determined whether the event constituted binding, lockup, or kickback, as follows:

Binding: Significant and abrupt slowing of steering wheel rotation from a rate of about 1000 degrees per second (about 3 full rotations of the steering wheel in one second) to a level on the order of 100 degrees per second within a time frame of about 200 milliseconds, but during which the steering wheel did not come to a complete rotational stop.

Lockup: Significant and abrupt slowing of steering wheel rotation from a rate of about 1000 degrees per second to a complete rotational stop within a time frame of about 200 milliseconds, followed by a stationary position for 30 to 100 milliseconds, and finally, continued rotation of the steering wheel in the original direction.

Kickback: Significant and abrupt slowing of steering wheel rotation from a rate of about 1000 degrees per second to a complete rotational stop within a time frame of about 200 milliseconds, and in spite of continued driver effort, reverse rotation of the steering wheel caused by counter torque in the steering system. These events are rapidly followed by a second complete stop of the steering wheel, then by rotation in the original direction as the driver continues to apply torque in that direction.

The tabulation of test results for the volunteer drivers were reviewed to evaluate their significance. In so doing, certain statistical tests were applied to determine whether the results for the unmodified Crown Victoria were significantly different from the results for the Caprice peer vehicle. The differences between the numbers of steering binding, lockup, and kickback incidents in the unmodified Crown Victoria versus the Caprice vehicle were determined to be statistically significant. In one sense, however, the assessment of what those differences represent is subjective, other than the fact that the unmodified Crown Victoria consistently required more driver work than did the Caprice to successfully negotiate the test course.

On the other hand, the differences were not statistically significant between the numbers of incidents in which the driver lost vehicle control, or failed to stay in the test course lane in the unmodified Crown Victoria versus like numbers for the Caprice. Stated another way, the results showed that the volunteer drivers were as successful in retaining control of the unmodified Crown Victoria as they were in controlling the Caprice during the test runs. These test results are considered to be more important than the "feel" of the steering wheel, because they address more directly the real-word issue of crash avoidance.

Having previously noted that each test run typically presented at least three supertorque events, it follows that the 835 test runs provided approximately 2,500 total opportunities for exceeding the response capability of the power steering system. Similarly, the numbers of such opportunities for the respective vehicles are 882 for the unmodified Crown Victoria, 918 for the modified Crown Victoria, and 705 for the Caprice. If rates or percentages of steering wheel binding, lockup, and kickback events were computed based on the numbers of opportunities, rather than numbers of test runs, those rates or percentages decrease by a factor of three. For example, the unmodified Crown Victoria demonstrated an "binding" rate of 17.01 percent when based on number of test runs, but that rate becomes 5.67 percent when based on the 882 supertorque opportunities during those runs. Another simply stated finding is that the test drivers lost control a total of only three times out of 882 opportunities to "crash;" this represents their collective ability to avoid a crash in 99.66 percent of those instances.

Each of the volunteer drivers was interviewed after completion of the driving exercise, using a set of questions developed to ensure that each driver was given a consistent set of issues to discuss. These questions gave each driver an opportunity to express an opinion regarding the steering system performance for each of the three vehicles driven. From their responses it was found that the percentage of drivers who complained about the steering performance varied, depending on the order in which they drove the three test vehicles. For example when the unmodified Crown Victoria was driven first, 78 percent of the volunteers complained about the steering response, as compared to 0 percent for the Caprice when driven first in the sequence. However, when the unmodified Crown Victoria was driven last in the order, 29 percent complained about the steering, as compared to 8 percent for the Caprice when driven last. Overall, the "complaint" rates were 13 percent for the Caprice, 18 percent for the semi-modified Crown Victoria, and 53 percent for the unmodified Crown Victoria.

The "complaint rates" were determined from the subjective and verbal assessments of steering response of the test vehicles by the drivers. On the other hand, the data tabulated above regarding loss of vehicle control are objective, in that they are based on actual "crash" incidents, as denoted by vehicle impact with one or more of the test course pylons.

SLALOM AND LANE CHANGE TESTS:

A series of evasive maneuver tests using professional drivers was conducted. In these tests, the vehicles were driven through a series of "gates" at incrementally increasing speeds, so as to simulate three scenarios, each of which required rapid and successive reversals of steering direction. These tests were designed to assess the thresholds of vehicle speeds at which performance of the power steering system ceased to be the primary issue affecting vehicle controllability. It was recognized that as vehicle speed increases, the angular excursion and rate of rotation of the steering wheel required to perform a lane change

maneuver must decrease in order to retain tire traction with the road surface. With rapid and large steering inputs as vehicle speed increased, uncontrolled yaw would result; an event beyond which steering system lockup or binding has no significance.

Descriptions of the evasive maneuvers test scenarios are detailed in the aforementioned VRTC test report. These procedures are described as slalom tests using two configurations, and lane change tests using three configurations.

The slalom tests demonstrated that steering tests of the subject vehicles must utilize appropriate initial vehicle speeds and sufficiently short gates in order to create the onset of the alleged defect. If these two conditions are not met, evasive maneuvers can be successfully executed without a steering wheel input rotation rate sufficient to create an abnormality in the steering response.

Specifically noted were the findings that the alleged steering defect occurred before the vehicle reached its threshold of apparent tire traction loss with 30 ft and 40 ft gates, both of which required rapid and aggressive steering inputs. With the longer 50 ft and 60 ft gates, requiring less rapid and less aggressive steering inputs, the steering anomaly and loss of tire traction occurred at about the same speeds.

ADDITIONAL INFORMATION:

INFORMATION SOLICITED FROM LAW ENFORCEMENT AGENCIES:

Specific actions were taken to solicit information relevant to this investigation from the law enforcement community. Meetings were held, dialogue with police authorities were sought, and a targeted survey of selected law enforcement agencies was conducted.

On April 18, 1994, NHTSA representatives met with Prince Georges County (Maryland), Police Department (PGCPD) officials. The nature of NHTSA's concerns were discussed and PGCPD provided several of the subject vehicles for driving maneuvers so that the alleged steering phenomenon could be experienced by NHTSA staff personnel. The vehicles were not instrumented, but the qualitative assessments were useful in understanding the basic "feel" of the alleged defect. In addition, limited discussions were held regarding the separate fatal crashes of two PGCPD officers in single-vehicle incidents while operating the subject vehicle models. These incidents were critically reviewed by NHTSA and the findings of those reviews are discussed under Accident Reconstructions, in this report.

On April 21, 1994, NHTSA staff met with the Bergen County (New Jersey) Prosecutor and Executive Assistant Prosecutor to discuss the specifics of the fatal incident involving the Paramus, New Jersey, officer which precipitated this investigation. In addition to the details and forensic reports regarding that incident, information was also provided to NHTSA regarding police driver training exercises utilized in Bergen County, and the precision

maneuver exercises which allowed the alleged defect to be demonstrated consistently and repeatably under controlled circumstances.

On April 24, 1994, NHTSA issued the first of two notices over the nationwide police electronic telecommunications system. The purpose of this notice was to advise the law enforcement community of the initiation of the subject investigation, and to solicit input from those agencies regarding any incidents known or reported to have resulted from diminished power steering assist in the subject vehicles. A second notice of similar nature was issued on September 15, 1994, to again solicit such reports from law enforcement agencies across the Nation. In response to these solicitations, over 100 contacts were received from law enforcement agencies. None, however, reported an incident in which the alleged defect had been definitively and officially established as causal or contributory to a crash incident. These notices were significant in that they effectively represented a survey of 100 percent of users of the subject vehicles, and none provided an affirmative report of the alleged defect in actual service, as previously indicated.

SURVEY OF LAW ENFORCEMENT AGENCIES:

A specific effort was made to formally contact and request certain information from selected law enforcement agencies. NHTSA contacted each of the selected agencies by letter, with questions regarding any known or reported incidents attributable to diminished power steering assist. Also considered important was an inquiry regarding the prevailing opinions and/or attitudes among officers as to whether the subject vehicles were suspected to have power steering characteristics that may cause them to be perceived as "unsafe."

Responses to the letter survey were consistently negative. The specific letters from NHTSA, and the responses thereto, have been placed in the public record of this investigation.

REVIEW OF NHTSA ACCIDENT DATA:

NHTSA's National Center for Statistics and Analysis was asked to search its State accident data files, and the Fatal Accident Reporting System (FARS) files, to review the involvement of the subject vehicles in fatal and non-fatal single- and multiple-vehicle crashes. As is normally the case when such data reviews are conducted, this effort was intended to determine whether there were any apparent trends of over-involvement of the subject vehicle group in crashes of a type that might suggest a potential causal relationship between those crashes and the alleged defect.

NCSA's review of the accident data and the statistical tests to evaluate the significance of that data, disclosed conflicting results. The studies included both police and consumer vehicles in the analyses, and generated the following findings:

1. For the 1987-1991 model years, Florida state data indicates that more Crown Victorias were involved in single-vehicle accidents than expected. In FARS, for the same model years, fewer Crown Victorias were involved in fatal crashes than expected. For these model years, an "indeterminable" conclusion was reached.

2. For the 1992-1994 model years, NCSA found that data from two states (Missouri and Florida) indicate the Crown Victoria to be over represented in single vehicle crashes.

NCSA concluded that "... while the data does show some significant results in regarding relationships among model year and single/multiple vehicle crash type, there are no consistent patterns." As they relate to this investigation, NCSA's findings do not support or provide evidence that the subject vehicles have experienced power steering malfunctions that may have contributed to crashes.

ACCIDENT RECONSTRUCTIONS:

Independent reconstructions of selected police vehicle crash incidents were performed. Under contract with NHTSA, the Calspan Corporation provided expert reviews and detailed reconstructions of six incidents involving the subject vehicles, as follows:

1. Bergen County, New Jersey, one fatal;
2. Prince Georges County, Maryland, two fatal;
3. Toronto, Ontario, Canada, one fatal; and
4. Harrison, New York, two non-fatal.

The detailed reconstruction reports submitted by Calspan to NHTSA have been placed in the public file for this investigation. The reconstructions included review of police accident and other reports, on-site inspections, interviews as appropriate, and analytical exercises to establish important crash parameters. The alleged defect was not found to have been a probable cause leading to the occurrence of any of the crashes included in this detailed review.

The following are brief summaries of the specific circumstances and findings regarding the six accidents reviewed:

1. Vincent R. BROCK, Paramus, New Jersey: (Fatal). 1992 Crown Victoria police sedan. This crash occurred when the driver of the subject vehicle, while responding to an emergency police call, initiated a lane change maneuver that was the first of a series of events which resulted in a loss of vehicle control. The travel path of the subject vehicle was such that it entered uncontrolled yaw at a computed speed of 65 mph, and impacted a light standard at the left side B-pillar.

Reconstruction of the sequence of events in this fatal crash included review of the forensic report prepared by the American Standards Testing Bureau for the Bergen County Prosecutor, as well as analysis of all other available information and data. Calspan's reconstruction concluded that the evidence does not support the theory that the alleged defect was a causative or contributory factor in occurrence of this crash.

2. John L. BAGILEO, Prince Georges County, Maryland: (Fatal). 1993 Crown Victoria police sedan. The police investigation of this incident concluded that excessive speed, computed to be 104 mph, was a major factor in causation of this incident. Calspan's analysis concurred with this finding, and found no evidence to indicate that the alleged defect in the steering system was a contributor to the crash.

3. Roger P. FLEMING, Prince Georges County, Maryland: (Fatal). 1992 Crown Victoria police sedan. This incident involved high-speed (100+ mph) pursuit during which the subject vehicle struck a curb. The police investigation concluded that a road defect (curb) was the primary accident cause. Calspan's analysis concluded that the alleged defect was not a contributing factor in the causation of this crash.

4. Peter SCHIRMER, Harrison, New York: (Non-fatal). 1992 Crown Victoria police equipment sedan. Calspan noted discrepancies between the driver's reconstruction of the sequence of events and the police reconstruction. Analysis of the evidence indicated several possible scenarios of the vehicle's travel path and initial velocity. Calspan's conclusion expressed doubt that the alleged steering defect contributed to the impact sequence.

5. Steve DiLAURIA, Harrison, New York: (Non-fatal). 1992 Crown Victoria police equipment sedan. Based on the mechanics of the crash, Calspan concluded that the front tires were locked just prior to impact and for this reason, the vehicle could not respond to a steering input. Therefore, if any steering anomaly had occurred at this point, it would have played no role in causation of the crash.

6. City of Scarborough, Ontario, Canada: (Fatal). 1992 Crown Victoria police equipment sedan. The reconstruction concluded that the primary causal factor in this incident was the high rate of speed at which the Crown Victoria was traveling, while in pursuit of a stolen

vehicle. A lane change maneuver was required in the sequence of the Crown Victoria's path but its severity is not known. Three possible pre-impact scenarios for the Crown Victoria's path were developed, due to certain evidentiary information that could not be validated. Nonetheless, the vehicle speed was computed to be between 82 and 102 mph during the sequence of events, and contact occurred between the left front tire and a curb. The critical maneuver was found to be the Crown Victoria driver's action to avoid impacting another police vehicle, which placed the subject vehicle on a collision course with a light standard. All steering inputs beyond that point could have redirected the heading angle of the subject vehicle but would not have changed the heading of its center of gravity. Thus, if any steering anomaly occurred after the initial left input, it would not have been a factor in causation of the fatal crash.

WARNING SYMPTOMS:

There are no known or reported indicators or symptoms which give warning of the alleged defect. The alleged defect is an anomaly in the performance of the power steering assist system which becomes apparent to the vehicle operator only under circumstances of extremely aggressive, precision vehicle maneuvers. It is not exhibited under normal driving circumstances, and is apparent only if the road wheels/tires have proper traction with the road surface. In addition, manifestation of this performance anomaly requires that the vehicle operator possess sufficient upper body strength and be highly adept in maneuvering the vehicle so that the limit of its handling capabilities are approached.

CONTRIBUTING FACTORS:

The alleged defect, a steering system performance anomaly identified through vehicle testing, occurs when a combination of several factors exist. In addition to the design of the steering system itself, also critical are the suspension characteristics unique to police equipment package vehicles, and the operational circumstances in which the vehicle is placed.

It is foreseen, and validated by interviews with police officers who volunteered as drivers in the tests conducted, that precision maneuvers as required in those tests are representative of driver actions that may be necessary during police work. Such driving maneuvers are not seen as the norm, but rather the type of actions that may become necessary during emergencies or in precision pursuit circumstances such as might exist in urban traffic.

FAILURE/MALFUNCTION MODES:

In a strictly technical sense, a "malfunction or failure" of the power steering assist system does not occur. This investigation disclosed that the issue of concern is more appropriately characterized as involving the driver's expectation of vehicle response to a certain level of steering input.

As established through NHTSA's engineering tests of instrumented Crown Victorias, the "failure" or "malfunction" occurs when the internal restrictions of fluid flow through the power steering gear results in a delayed response of the power assist system. When this occurs, the amount of steering input torque required to maintain vehicle control may increase four-fold, without a noticeable and corresponding change in vehicle turning response. This phenomenon may be perceived as lockup or binding of the power steering system because the vehicle does not turn as the driver anticipates that it should.

MANUFACTURER'S EVALUATION OF THE ALLEGED DEFECT:

NHTSA staff personnel met with representatives of Ford's Automotive Safety Office, as well as technical personnel with power steering system design responsibilities on May 31, 1994, during the PE phase of this investigation. The purpose of the meeting was to discuss technical and design details, as well as performance characteristics, of the subject power steering assist system. The meeting was followed by a series of driving exercises at Ford's test facilities, to qualitatively assess various circumstances and maneuvers during which the alleged defect would, or would not, occur.

The manufacturer has consistently held the position that the design and/or performance of the power steering system installed in the subject vehicles are not deficient so as to represent a safety-related defect. Articulation of Ford's position regarding this issue, together with the detailed basis for this position, were provided by letters dated June 3 and June 13, 1994, during the PE phase of this investigation. That information has also been placed in the public file.

In support of its position regarding the performance of the subject power steering system and in response to a verbal request from NHTSA, Ford conducted an independent analysis of the accident experience of the subject vehicles as compared to its primary peer vehicle. The analysis was based primarily on data from NHTSA's FARS files, and showed the fatal accident experience of the 1992-1993 Crown Victoria to compare favorably with that of the Chevrolet Caprice police vehicle. The analysis concentrated, however, on incidents which involved high-speed, pursuit-type situations. The details of that analysis were provided to NHTSA by letter dated November 17, 1994.

SUMMARY OF FINDINGS:

Performance of the power steering assist system in the 1992 and 1993 Ford Crown Victoria police package vehicle is such that a brief partial or total loss of power assist may be experienced by certain drivers, as follows:

1. In the low to moderate speed range of approximately 15 to 40 mph.

2. During rapid and successive changes in the direction of steering wheel rotation.

3. With no prior warning of impending anomalous steering behavior. When the capability of the system to respond as the driver anticipates is exceeded, there is a quantifiable lag in that response.

4. In a repeatable and reproducible manner, which can be readily demonstrated.

5. As a results of restricted fluid flow within the steering gear.

6. In police package vehicles only, as the consumer version of these vehicles will enter uncontrolled yaw before the onset of the steering system anomaly.

7. During highly aggressive, precision maneuvering of the subject vehicles, after more than one complete reversal of steering direction.

When steering system lag is perceived, the driver effort at the steering wheel may increase by a factor of approximately four times the normal torque required for vehicle control. During this realm of extremely high torque application, the system may exhibit binding, lockup, or kickback of the steering wheel.

Producing the steering anomaly (the alleged defect) requires a high rate of steering wheel rotation, typically on the order of 800 to 1000 degrees per second (2.2 to 2.8 rev per second of the steering wheel). It also requires a significant angular movement of the steering wheel at the high rotation rates during turning maneuvers; both of these factors are limited by a maximum vehicle speed at which tire traction and vehicle control can be maintained with such severe steering inputs. At the onset of uncontrolled vehicle yaw during such aggressive

turning maneuvers, the steering anomaly becomes inconsequential.

When a group of active police officer volunteers were exposed to the steering anomaly with no prior warning of its onset, all were able to successfully maintain control of the test vehicle and traverse a prescribed road course; although not necessarily during their first test run. These volunteers, when confronted with the alleged defect in an unforewarned driving exercise, were able to control the 1992 Crown Victoria police vehicle equally as well as they were able to control a Chevrolet Caprice peer vehicle.

The law enforcement community as a group apparently does not perceive the alleged defect as a significant safety-related issue. Similarly, there is no documentation available to demonstrate that the alleged defect has resulted in a single fatal or nonfatal police vehicle crash. Independent reconstructions of six specific incidents. where the alleged defect was a possible contributing factor, concluded that there were no causal relationships in any of those instances. Finally, review and analysis of fatal and nonfatal accident statistics do not conclusively show that the subject vehicles have been over represented in crashes that may have resulted from the alleged defect.

REASONS FOR CLOSING:

The particular performance characteristics of the subject steering system may present a brief loss of power assist during extremely aggressive but foreseeable driving maneuvers. The collective body of information disclosed or developed during this investigation shows that this performance does not represent a significant threat to motor vehicle safety.

The performance of the power steering assist system installed in 1992 and 1993 Ford Crown Victoria police vehicles is adequate under all but the most extreme operating conditions and does not establish the existence of a safety-related defect within the meaning of the National Traffic and Motor Vehicle Safety Act of 1966.