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PARAMETRIC ANALYSIS OF LIGHT TRUCK AND AUTOMOBILE MAINTENANCE

D.A. Hurter
N.C. Gardella
P.G. Gott

Arthur D. Little Inc.
Acorn Park
Cambridge MA 02140

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16. Abstract

Utilizing the Automotive and Light Truck Service and Repair Data Base developed in the companion report, parametric analyses were made of the relationships between maintenance costs, scheduled and unscheduled, and vehicle parameters; body class, manufacturer, engine size, vehicle weight, model year and facility type. The computer generated parametric graphs are included in the appendices.

Technological innovations, including radial tires, lightweight bodies, fuel injection and catalytic converters, exhaust gas recirculation, high energy ignition, electronic control, diesel, stratified charge, stirling cycle, gas turbine and transmission modifications were analyzed for their impact on the future trends in maintenance costs. A methodology was developed for the assessment of component durability along with a determination of the failure modes of high volume aftermarket items as a basis for the evaluation of the impact of future technological innovations on maintenance costs.

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PREFACE

This development and analysis of the Repair and Service Maintenance Data Base was performed for the U.S. Department of Transportation, Transportation Systems Center by the Automotive Technology Group at Arthur D. Little, Inc., under Contract Number DOT-TSC-1047. The work was done under the guidance of Mr. Samuel F. Powel, Miss Holly Deblois, and Mr. James Kakatsakis, Technical Monitors at DOT/TSC. The Program Manager was Donald A. Hurter, assisted by Nancy Gardella and Philip Gott.

We would like to thank the Chilton Publishing Company, and, in particular, James Milne, as well as many others in the automotive industry for their contribution to the development of the vehicle maintenance data base.

A companion report "Data Base Development of Light Trucks and Automobile Maintenance" DOT-TSC-NHTSA-78-25 Volumes I, II and III (HS 803-376) presents a data base of the automobile and light truck service and repair industry and the current maintenance requirements of 212 domestic and foreign cars and light trucks through the years 1970-1975. This report presents a parametric analysis of the maintenance requirements of vehicles; a plan by which the impact of new technologies on maintenance requirements may be assessed; the application of that plan to certain new innovations; and an analysis of the best selling replacement parts to determine the cause of their failure.

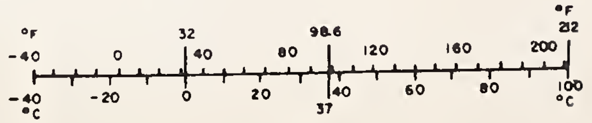
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. EXECUTIVE SUMMARY

1.1 PARAMETRIC ANALYSIS SUMMARY

The relationship between the maintenance costs and the vehicle parameters were examined both on the computer generated graphs and separately averaged life cycle costs. The following general conclusions were developed.

1.1.1 Scheduled Maintenance

The overall average scheduled maintenance cost over a vehicles' life time is $1100.

a. Body Class Comparison

With the exception of the subcompact class the smaller the body class the less costly it is to perform the scheduled maintenance

b. Vehicle Weight Comparison

Similarly for the weight comparison the lighter the car, the less costly to maintain, however, the 1500-2600 pound category does not follow this trend for Chrysler or Ford , due to their use of imported cars in this category.

c. Engine Size Comparison

As it logically follows, the engine class comparison yielded the same result, the smaller the engine the less expensive except for < 150 CID engine class

d. Facilities Comparison

Across the range of body classes the dealer has the highest cost for performing scheduled maintenance next is the independent repair then service stations

e. Manufacturers

Both Ford and General Motors experience a two year jump in their scheduled maintenance costs at the time of changing emission regulations

Subsequent to this rise , both manufacturers extended in general the length of their maintenance intervals causing a significant decline in scheduled miantenance life cycle costs.

General Motors has typically the most expensive recommended maintenance program, followed by Chrysler, American Motors and then Ford

1.1.2 Unscheduled Maintenance

The overall average for unscheduled maintenance costs over a vehicle's lifetime is $2300.

With the universally defined frequency factors, the significant variations are caused by the differences in parts costs and labor times among body class. Again, the general trend holds that the smaller the vehicle the less expensive it is to maintain except in the case of the subcompact and mini-class.

1.2 FUTURE MAINTENANCE COST TRENDS

Table 1-1 presents a summary of the impacts of future technology on automobile maintenance. As shown in the Table, the majority of the technological innovations will reduce or will not affect maintenance costs. With the exception of five innovations, the greatest impact on the service industry will be in retraining of mechanics, with seven of the fourteen innovations having little or no impact on the industry.

These innovations which are expected to increase maintenance costs do so largely because of the requirement to replace expensive parts, and not due to the increased maintenance requirements. For example, the use of electronically controlled carburetion or fuel injection has the potential of decreasing the number of times a fuel system tune-up is required. The increased costs result from replacement of more expensive, major components. Replacement frequencies should not, however, increase as a result of these innovations.

The stratified charge engine is also listed as increasing maintenance costs. This is primarily due to the use of fuel injection equipment or the increase in the number of engine valves. These systems are expected to require replacement (fuel injection) or adjustment (multiple valve) at the same frequency as carburetors or valves, respectively, on conventional engines. The increase in costs is due to the replacement of more expensive equipment or an increase in the labor time involved in normal adjustments.

The introduction of electronic controls, fuel injection, diesels, and gas turbines are expected to require new diagnostic tools as well as significant retraining of mechanics. The last decade has shown tremendous growth in diagnostic instrumentation even for conventional engines, and, in general, the use of diagnostic tools has been accepted by the repair and service industry as well as the consumer. Furthermore, when these diagnostic tools have been used as part of a routine tune-up or other repairs, we have found that their use has not resulted in an increase in the repair fee. The equipment is generally amortized through an increase in productivity rather than through increased charges. Therefore, the new diagnostic equipment is not expected to increase repair costs.

TABLE 1–1 IMPACT OF FUTURE TECHNOLOGY ON REPAIR AND SERVICE INDUSTRY AND LIFE CYCLE MAINTENANCE COST

Technology	Maintenance Cost Impact			Industry Impact			
	Lower	Same	Higher	None	New Skills	New Facilities	New Diagnostics
Radial Tires		X		X			
Light Weight Design		X		X			
Materials Substitution	X				X		
Lower Engine Speeds		X			X		
Three Way Catalytic Converters		X			X		
High Energy Ignition		X		X			
Proportional EGR		X		X			
Fuel Injection			X		X		X
Electronic Controls	X				X		X
Lightweight Diesels	X				X		X
Stratified Charge			X	X			
Gas Turbine	X				X		X
Stirling Engine	X				X	X	X
Four-Speed Lockup Automatic		X		X			

It is also interesting to note that both the diesel and gas turbine engines use a fuel injection type of fuel control and distribution system. Therefore, it is most probable that a shop which has invested in a set of diagnostic equipment for fuel injection equipment will already be at least partially equipped to handle any engine with this type of fuel control. A completely separate set of diagnostic tools for alternate engines will not be required.

The only new technology which will cause a great, and presumably very expensive change in the repair and service industry is the Stirling engine. With their completely sealed, high pressure working fluid, these engines are completely different than any other type of engine the repair and service industry has ever handled. New storage and distribution systems will be required for the working fluid. High pressure charging facilities and accompanying safety equipment will also be required.

Since the percentage of the fleet which is equipped with Stirling engines will undoubtedly be quite small for the first five or so years after its introduction, the cost for these new facilities would be quite high relative to the number of cars that are available to use. If the costs for these facilities were to be amortized over only the fleet of Stirling powered vehicles, there would be a dramatic increase in maintenance costs. However, we feel that the successful introduction of any new technology such as the Stirling depends upon competitive maintenance costs. Therefore, we conclude that even though the required new facilities would be expensive, their cost would not be totally amortized by the Stirling fleet, but would either be spread out over the entire vehicle fleet, or reflected in the initial cost of the car.

1.3 DURABILITY SUMMARY

In assessing the durability and determining the failure mode of any vehicle component, system, or new innovation, those factors beyond the control of the vehicle designer must be considered. Actual component life is reduced from the design life goal of 100,000 miles due to changes in the operating or environmental conditions of the component or system. Such factors which limit the durability of a component are:

- Styling, as it influences
  - engine bay size
  - wheel diameter
  - aerodynamic drag
- Temperature Extremes
- Vehicle Weight, as it influences
  - engine loading
  - drivetrain loading
  - brake loading

- Wheel Diameter, as it influences
  - drivetrain rotational speed
  - swept area of brakes

1.4 COMPONENT FAILURE MODE SUMMARY

The large volume aftermarket items, and their modes of failure have been determined. Exhaust system components comprise the largest unit volume in the automotive aftermarket. When exhaust systems are grouped with the scheduled maintenance items of filters and ignition components they make up approximately 50% of the aftermarket unit volume.

Failure modes of the large volume aftermarket components are:

- Deterioration due to aging
- Contamination by dirt and water
- Failure due to extreme temperatures
- Failure of gaskets and seals
- Normal wear
- Loss or degradation of lubricant
- Bearing wear and failure due to overload

An analysis of the most probable failure modes of a component must consider the vulnerability of the components' materials, electrical system, and/or moving parts to those possible conditions leading the component failure.

2. INTRODUCTION

2.1 BACKGROUND

Since the mid 1960's, the automotive industry has had to equip its automobiles with an ever increasing amount of hardware and equipment in order to meet regulatory standards for safety and emissions. This trend towards increasingly complex light duty motor vehicles is expected to continue until at least the mid 1980's, and probably beyond, due to the impact of regulatory requirements such as more stringent emission standards, improved fuel economy, and increased crashworthiness and accident avoidance. The associated hardware and equipment necessary to meet the regulatory requirements has undoubtedly increased the first cost as well as the life-cycle costs of automobiles.

In order to assess just what the impact of future regulatory requirements will be upon vehicle life cycle maintenance costs, the United States Department of Transportation, Transportation Systems Center (DOT-TSC) desired to establish a data base of current (1970-1975) vehicle repair and service costs, and to determine just how the introduction of technological innovation can impact these costs. In addition, they desired the development of a methodology to assess vehicle component durability for use in evaluating the maintenance cost impact of future innovations or regulatory requirements.

2.2 PURPOSE

The Transportation Systems Center engaged Arthur D. Little to prepare a data base examining the typical life cycle maintenance (100,000 mile) costs of servicing and repairing each of 212 different sales leading cars and light duty pickup trucks, to develop complete cost characterization of four representative service facilities and to analyze the service industries' pricing policies. The companion to this report* covers these major areas.

The analysis of relationships between maintenance costs and vehicle parameters, the estimation of the impact of various technological innovations upon these costs in order to establish future trends in maintenance costs are developed as the next step toward understanding the important factors affecting maintenance costs. Both the evaluations of component failure analysis and a methodology for assessing vehicle component durability were developed in order to provide DOT-TSC with the basis for assessment of the impact of future technological innovations. This report contains these four topics.

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*"Data Base Development of Automobile and Light Truck Service and Repair" DOT-TSC-NHTSA-78-25 Volumes I, II and III (HS-803-376)

2.3 SCOPE

To place the scope of this report in proper context and relationship to the companion report, DOT-TSC-NHTSA-78-25, the scope of the latter report is briefly summarized as follows:

Maintenance costs, both scheduled and unscheduled were developed by:

- Specific vehicle - 212 1970-1975 vehicles
- Type of repair establishment
  - Dealer
  - Gasoline service station
  - Independent repair garage

Representative facilities costs were characterized by:

- building
- land
- tools and equipment
- investment
  - inventory
  - operating capital

Industry pricing policies were analyzed by:

- dealer prices and discounts
- jobber price levels
- discounts
- stocking allowance

The scope of this report covers the subsequent tasks which are based on the data developed for the companion report, DOT-TSC-NHTSA-78-25.

2.3.1 Parametric Analysis

The scheduled and unscheduled maintenance costs were summarized over each vehicle's life cycle by computer and graphical comparisons.

The relationships between maintenance costs and each parametric category was presented by year of vehicle age.

2.3.2 Parameters:

- Manufacturer
- Body Class
- Model Year
- Engine size
- Vehicle weight
- Facility type

2.3.3 Future Trends in Maintenance Costs

An analysis was made of the trends in maintenance costs for the 1975-1980 and 1980-1985 time by analyzing the impact specific technological innovations and on the maintenance costs and the service and repair industry. The technological innovations addressed are:

- Radial Tires
- Lighter Weight Bodies
  - by design
  - by material substitution
- Improved Engine/Road Load Matching
- Engine Modifications Involving Catalytic Converter
  - including fuel injection
- Proportional Exhaust Gas Recirculation
- Electronic Engine Components
  - high energy ignition
  - electronic spark control
  - electronic fuel and air control
- Light Weight Diesel
- Stratified Charge - Spark Ignited Engine
- Stirling Cycle Engine
- Gas Turbine
- Lock up Torque Converter and Four-Speed Automatic Transmission

The trends assessed for each innovation were:

- Maintenance operations
- Maintenance costs
- Skill level required
- Tools and equipment required
- Additional diagnostic work

2.3.4 Methodology for the Assessment of Vehicle Component Durability

A methodology for assessing vehicle component durability was developed by examining basic design assumptions and various wear factors. Vehicle parameters determined by car size such as engine bay volume and vehicle weight were examined for their effect on durability. The results of this task contain a review of necessary assumptions, a developed list of forcing factors that affect wear and a technical discussion of the specific effects each factor would have that could limit the component's durability.

2.3.5 Failure Modes of High Volume Aftermarket Items

Existing historical data was used from recent surveys to develop a listing of high volume aftermarket items and their comparative volumes. The data presents a 7 year range in sales volumes. The cause of failure of each aftermarket item was examined and a small set of common factors, and conditions emerged as the primary causes of wear on various types of components. A methodology was established whereby a component can be divided into its generic parts (electrical, moving parts and lubricant) and each of these can be compared against a list of potential failure forcing conditions.

3. PARAMETRIC ANALYSIS

3.1 Discussion of Results

In order to analyze the detailed maintenance costs data and draw some general conclusions, the data was put into the form of a data base in a computer. This allowed the costs to be summed and averaged across various parameters; manufacturer, model year, body class, engine CID and weight class by labor, material and total costs categories. The scheduled maintenance costs could be applied and summed at the appropriate mileage/age interval resulting in graphs of scheduled maintenance costs performed at the dealer for each parameter by vehicle age. The unscheduled data, however, was summed as a simple total over the vehicle's life cycle.

The graphs contained in Appendix A listed in Table 3-1 were generated by the computer from the basic itemized cost data. Appendix B contains the list of vehicles represented and Appendix C contains the tabulation of which vehicles were summarized for each graph.

There are certain limitations in the possible interpretations to be made from these results due to the initial assumptions and the method of data development. For the scheduled maintenance where the manufacturers suggested maintenance requirements were used, several different effects can influence the summarized yearly maintenance. For example, changes in required maintenance due to additional components or systems as in the emissions check, reduction in scheduled replacement frequency due to increased durability, and changes in requirements as a marketing device all would result in a differential in the year to year maintenance. It is, therefore, difficult to define which of these or other effects are creating the variations observed across each set of parameters.

In the case of unscheduled maintenance, a common set of defined maintenance items and calculated frequencies was used for all vehicles except where inapplicable, as in the case of radiator repair for the air cooled Volkswagen Bug. Because of this commonality, variations in life cycle unscheduled maintenance costs reflect only parts costs differences and labor time differences.

3.2 SCHEDULED MAINTENANCE

3.2.1 Body Class Comparison

The first set of graphs examined are Figures A-1 to A-48 containing the scheduled maintenance data summarized by body class. Table 3-2 lists the approximate ranking from highest cost to lowest cost by body class, which seems to hold across the vehicle's age. In the materials column, as is expected, due to the more expensive parts, the luxury class is highest. The compact and subcompact, American categories are lowest along with the subcompact Japan which contains the Toyota and Datsun vehicles. The intermediate, truck, subcompact Volkswagen and standard categories fall in between. In general, it appears that the maintenance components for the Japanese subcompacts are less expensive than those for U.S. subcompacts and

TABLE 3-1 PARAMETRIC CATEGORY

Dealer Maintenance Costs

Figures	Abscissa	Ordinate		
1-48	Age	● Material ● Labor ● Total	Luxury Standard Intermediate Compact Subcompact USA Subcompact Foreign I, II Trucks	● Overall Average ● By Manufacturer
49-78	Age	● Material ● Labor ● Total	Vehicle Weight 4000 lbs 3601-4000 3201-3600 2601-3200 1500-2600	● Overall Average ● By Manufacturer
79-102	Age	● Material ● Labor ● Total	Engine Displacement 371 C.I.D. 301-370 151-300 30-150	● Overall Average ● By Manufacturer
103-105	Model Year	Scheduled Unscheduled Total	By U.S. Manufacturers	

TABLE 3-2 SCHEDULED MAINTENANCE COST RANKING BODY CLASS COMPARISON

	Material	Labor	Total
Highest	Luxury	Subcompact Japan	Luxury/Subcompact Japan
	Intermediate/Truck	Luxury	Intermediate/Truck
	Subcompact, VW	Intermediate/Truck	Standard
	Standard	Standard	Compact
	Compact/Subcompact USA/ Subcompact Japan	Compact	Subcompact USA/Subcompact VW
Lowest		Subcompact USA/Subcompact VW	

/Means classes are essentially equal in cost.

Subcompact USA = U.S. manufactured subcompacts.
Subcompact Japan = Toyota Corolla 1600/Datsun 610/510
Subcompact VW = VW Rabbit 1975 model year.

the Volkswagen components are the most expensive for subcompacts.

The labor components of the scheduled maintenance cost shows the surprising result that Japanese subcompacts have the highest labor component. This appears to be due to slighly higher labor times and more frequent intervals. The luxury body class labor costs are next highest, as the labor rates charged by luxury car dealers are higher. The remaining classes rank in the following order: intermediate/truck, standard, compact subcompact-USA/ subcompact Volkswagen.

When the material and labor are combined, the total resulting ranking is as shown in Table 3-2. The labor component of the subcompact Japan is large enough to cause them to rank highest along with the luxury vehicles. They are followed by the intermediate and truck categories then the standard compact and subcompact USA/VW. One expected result is the consistently higher costs for both material and labor for the intermediate as compared to the standard. The possible reason for this anamoly is the fact that each of the vehicles in the data is averaged into one of the respective categories. Therefore, some categories have more of one manufacturers' vehicles than others. This phenomena will tend to distort the actual relationship by introducing an imbalance in the averages. For example, there are more General Motors cars in the intermediate class category than in the standard body class category. Since General Motors has visibly higher scheduled maintenance costs, the intermediate category appears to be more expensive to maintain the larger size, heavier standard class. However, this is a faulty conclusion.

In order to evaluate the computer manipulated data without the distortion effects caused by averaged incompatible sets of vehicles, the total life cycle averages by body class and manufacturer were calculated for scheduled maintenance. The overall average life cycle cost is $1,100 for 10 years. Table 3-3 is a summary of the average life costs, both labor and material and Figure 3-1 shows the comparable graph of the relationship. The observed relationship is that the smaller the body class the lower the average life cycle maintenance costs. The variation in costs is due mainly to variations in parts costs and labor times, as the recommended maintenance items are essentially the same throughout a manufacturer's line.

Year to year cyclical variations can be seen by examining any of the individual total maintenance cost graphs. For example, in Figure A-17 to A-24, each average shows peak scheduled maintenance costs for the third, fifth and eight years with the lowest costs in the first and seventh year. At 100,000 miles per year the varying length maintenance intervals coincide in an uneven mode causing these peaks. For example, in a vehicle with recommended maintenance at 6,000, 12,000, 24,000, 30,000 and 36,000 mile intervals; performed in the third year will be two 6,000 mile inspections, one 24,000 mile inspection and one 30,000 mile inspection whereas the seventh year contains only one 6,000 mile inspection.

Table 3-3 TOTAL LIFE CYCLE SCHEDULED MAINTENANCE AVERAGES BY BODY CLASS AND MANUFACTURER

	BODY CLASS					
Manufacturer	Luxury	Standard	Intermediate	Compact	Subcompact	Truck
General Motors	1403	1341	1342	1238	1080	1247
Ford Motor	978	924	946	883	883	1056
Chrysler	-	1220	1174	1081	1154	-
American Motors	-	1060	1010	993	925	-
Japan	-	-	-	-	1368	-
	1190	1136	1118	1036	1082	1152

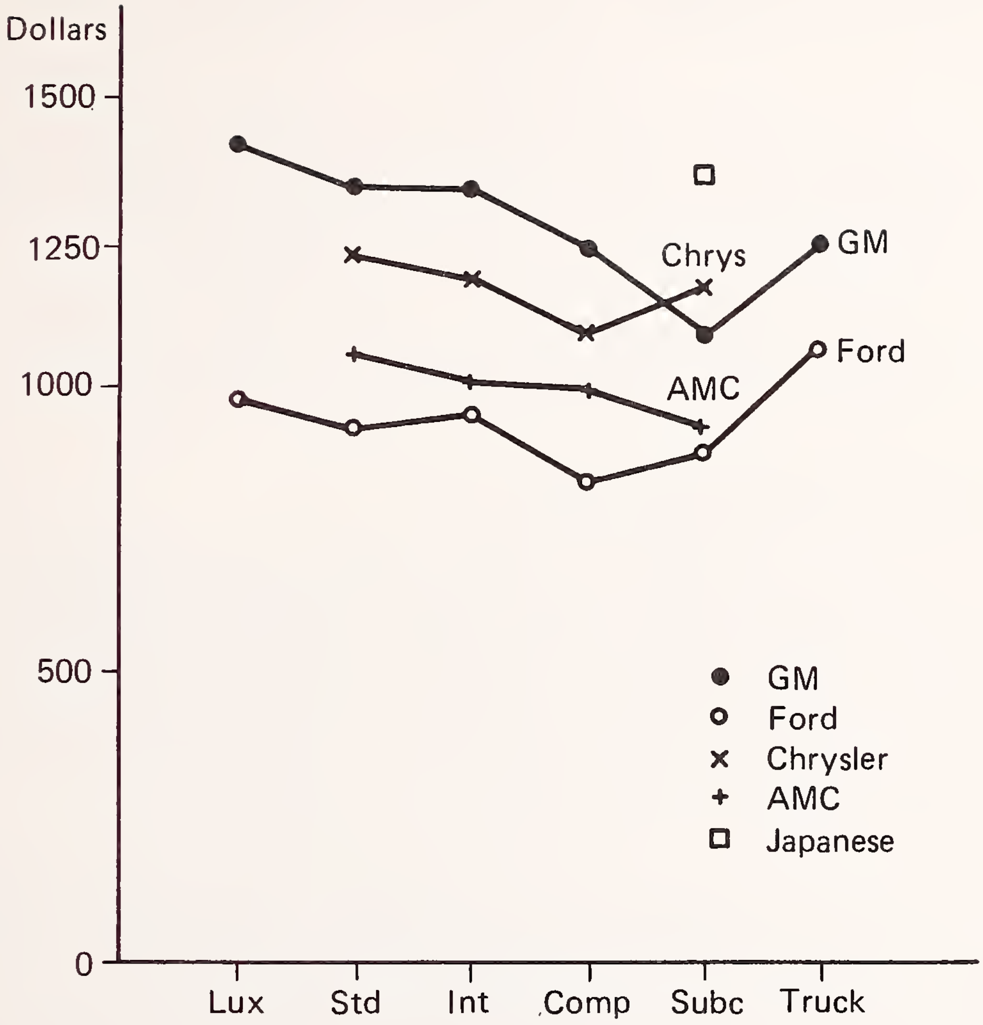

FIGURE 3-1. **LIFE CYCLE SCHEDULED MAINTENANCE COSTS BY BODY CLASS AND MANUFACTURER**

Reviewing Figures A-42 to A-48, the individual total costs averaged by manufacturer, one observation for the standard, intermediate, compact and subcompact classes is the fact that the intervals in Chrysler's maintenance schedule results in a constant level of maintenance costs from the second through the sixth year as opposed to the third and fifth year peak costs shown for General Motors, Ford and American Motors. All manufacturer's maintenance schedules result in very low maintenance costs for the seventh year.

The labor component of the maintenance costs, Figure A-33 to A-40 is generally the highest for General Motors and lowest for Ford with Chrysler and American Motors being equal in between. In contrast the material component, Figures A-25 to A-32, looks similar for Ford, Chrysler and American Motors, again with General Motors the highest. The only exception to this is the subcompact body class, Figure A-29, in which case American Motors material costs are the highest. This could be caused by the fact that the American Motors' Gremlin in the subcompact category has the largest subcompact engine, 232 CID, and is the heaviest subcompact vehicle.

3.2.2 Vehicle Weight Comparison

Similar to the set of graphs on body class are those averaged by vehicle weight class, Figures A-49 to A-78. Table 3-4 again ranks the overall categories from observable highest to lowest scheduled maintenance costs. Again the influence of the imbalance in manufacturers can be seen in the low rank 2601-3000 pound class which contains only four General Motors' models in its set of 37 vehicles, see Appendix C. In addition the influence of the high labor costs for the subcompact Japanese cars can be seen in the labor ranking.

Again the total life cycle data was averaged separately by manufacturers and weight class to eliminate the distortion. Table 3-5 contains the averaged total costs and Figure 3-2 the graphical representation. A trend similar to that shown by the body class comparison, Figure 3-2 is seen for vehicle weights > 4000 pounds down to 2601 pounds, where the lower the weight, the lower the life cycle cost. However, both Chrysler and Ford vehicles in the 1500-2600 pound category have higher costs than their respective 2601-3200 pound class vehicles.

3.2.3 Engine Size Class Comparison

Figures A-79 - A-102 in Appendix A show the detailed scheduled maintenance data by vehicle age and manufacturer. The relative ranking of the different CID categories is shown on Table 3-6 Once again, the smallest category

TABLE 3-4 SCHEDULED MAINTENANCE COST RANKING WEIGHT CLASS COMPARISON

	Material	Labor	Total
Highest	4000 pounds	4000 pounds	4000 pounds
	3601-4000/3201-3600	1500 - 2600	3601-4000/3201-3600/ 1500-2600
	1500-2600	3601-4000/3201-3600	
Lowest	2601-3200	2601-3200	2601-3200

/ Means classes are essentially equal

TABLE 3-5 TOTAL LIFE CYCLE SCHEDULED MAINTENANCE AVERAGES BY VEHICLE WEIGHT AND MANUFACTURER

	WEIGHT-POUNDS				
Manufacturer	4000	3600-4000	3201-3600	2601-3200	1500-2600
General Motors	1395	1238	1281	1081	1087
Ford Motors	952	1102	930	760	922
Chrysler	1219	1174	1168	1075	1154
American Motors	-	1032	1065	932	

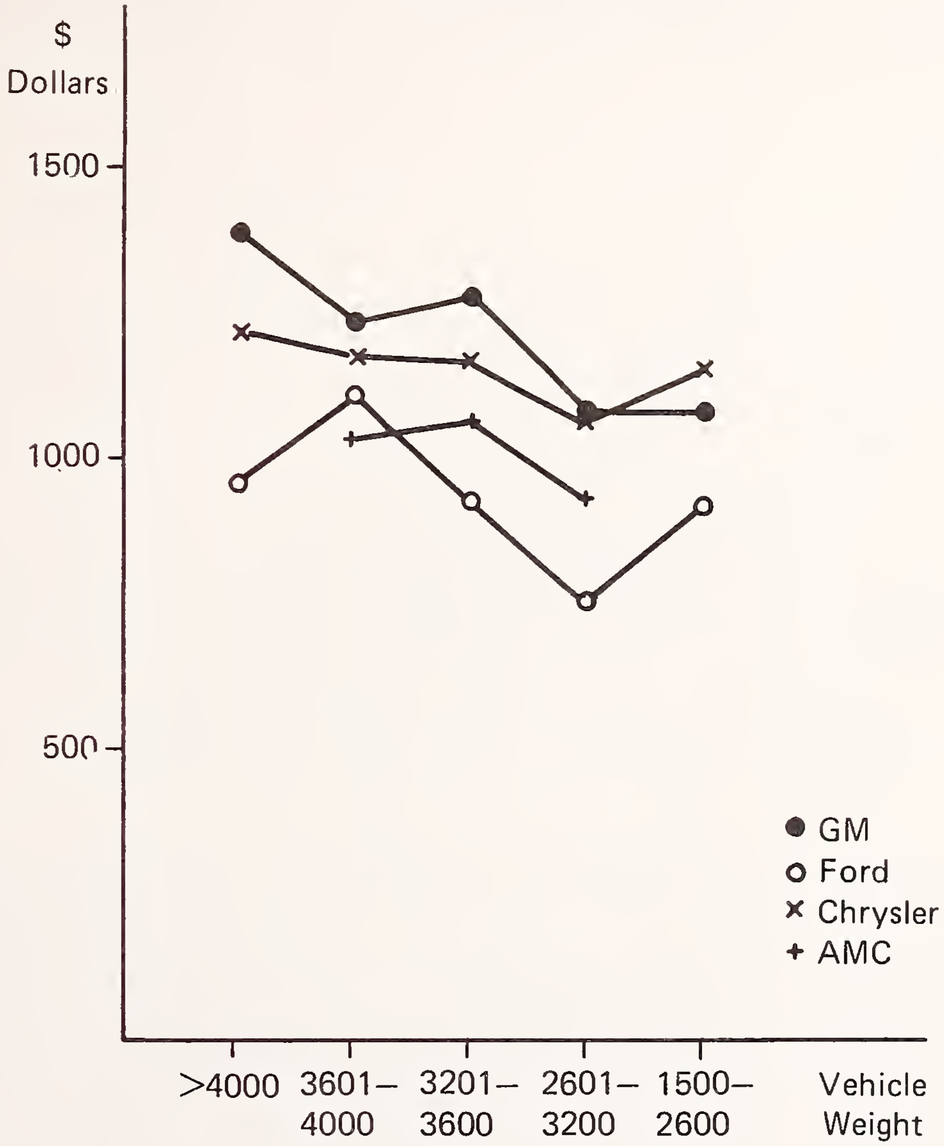

FIGURE 3-2. LIFE CYCLE SCHEDULED MAINTENANCE COSTS BY VEHICLE WEIGHT AND MANUFACTURER

TABLE 3-6 SCHEDULED MAINTENANCE COST RANKING - ENGINE SIZE CLASS COMPARISON

	Material	Labor	Total
Highest ↑	>371 C.I.D.	>371 C.I.D.	>371 C.I.D.
	301-370	50-150	50-150/301-370
	50-150	301-370	151-300
↓ Lowest	151-300	151-300	

/ Means classes are essentially equal.

50-150 CID ranks second highest in the year-by-year labor costs. Similarly, the low value for the 151-300 CID class is influenced by the fact that only 4 of the 37 averaged vehicles are General Motors. The computer generated total life cycle costs were again averaged to determine any significant trends in the relationships between engine size and scheduled maintenance costs. Confirming the conclusion from the body class and weight class comparison analysis, is the clear trend from 50-150 CID that the smaller the engine the less expensive the overall scheduled maintenance costs. The 371 CID engine sizes shows a rise in costs compared to the 150-300 CID category. (See Figure 3-3).

3.3 UNSCHEDULED MAINTENANCE

Unscheduled Maintenance by Body Class

Figure 3-4 shows labor, material and total unscheduled maintenance costs, averaged over the model years by body class performed at the dealership. The method in which the unscheduled maintenance data was developed, the definition of universal failure rates, and their application to each vehicle's parts and labor costs, determines the meaning of these results. The only substantial differences in the maintenance items performed on each vehicle result from differences in what scheduled maintenance was required by the various manufacturers. For example, if the scheduled maintenance called for "inspect spark plugs" but not "replace spark plugs" then the cost of replacing the spark plug would be included in unscheduled maintenance. However, some manufacturers required "inspect and replace spark plugs" as scheduled maintenance so they would not have a spark plug item in the unscheduled maintenance cost. Other exceptions are such as the VW Beetle which was air cooled in which case the radiator unscheduled maintenance item was not included.

Due to commonality in frequencies, the parts cost differences and labor time and rate differences are the cause of the variation seen across the body class spectrum. Again the influence of imbalance in number of manufacturers and General Motors' overall higher costs causes the false impression that the intermediate categories are more expensive than the standard categories. Included in the mini-class is the Honda Civic for years 1973, 1974 and 1975. Table 3-7 summarizes the ranking of each average body class by cost for unscheduled maintenance. The average total life cycle unscheduled maintenance costs are approximately $2300. over a 10 year 100,000 mile vehicle life.

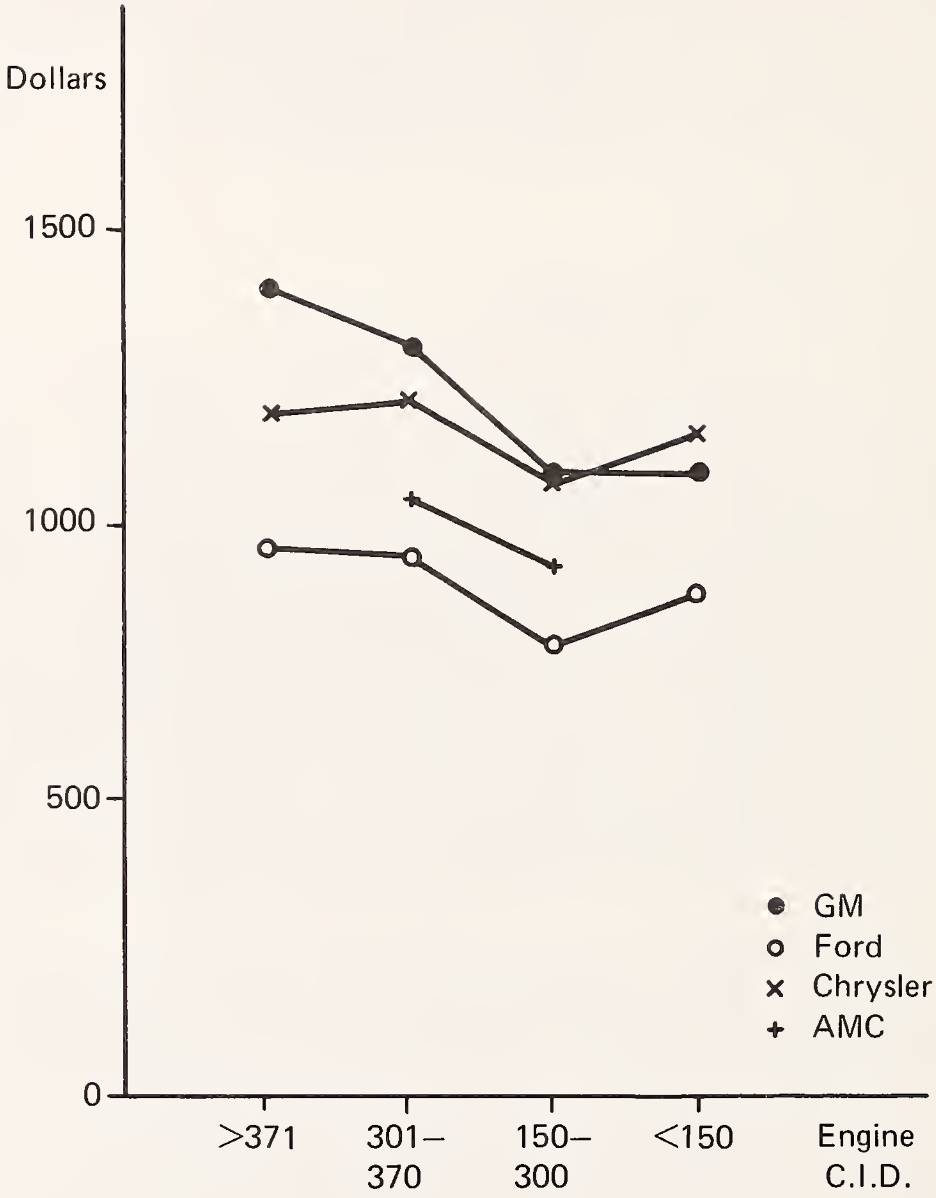

FIGURE 3-3. LIFE CYCLE SCHEDULED MAINTENANCE COSTS BY ENGINE CID AND MANUFACTURER

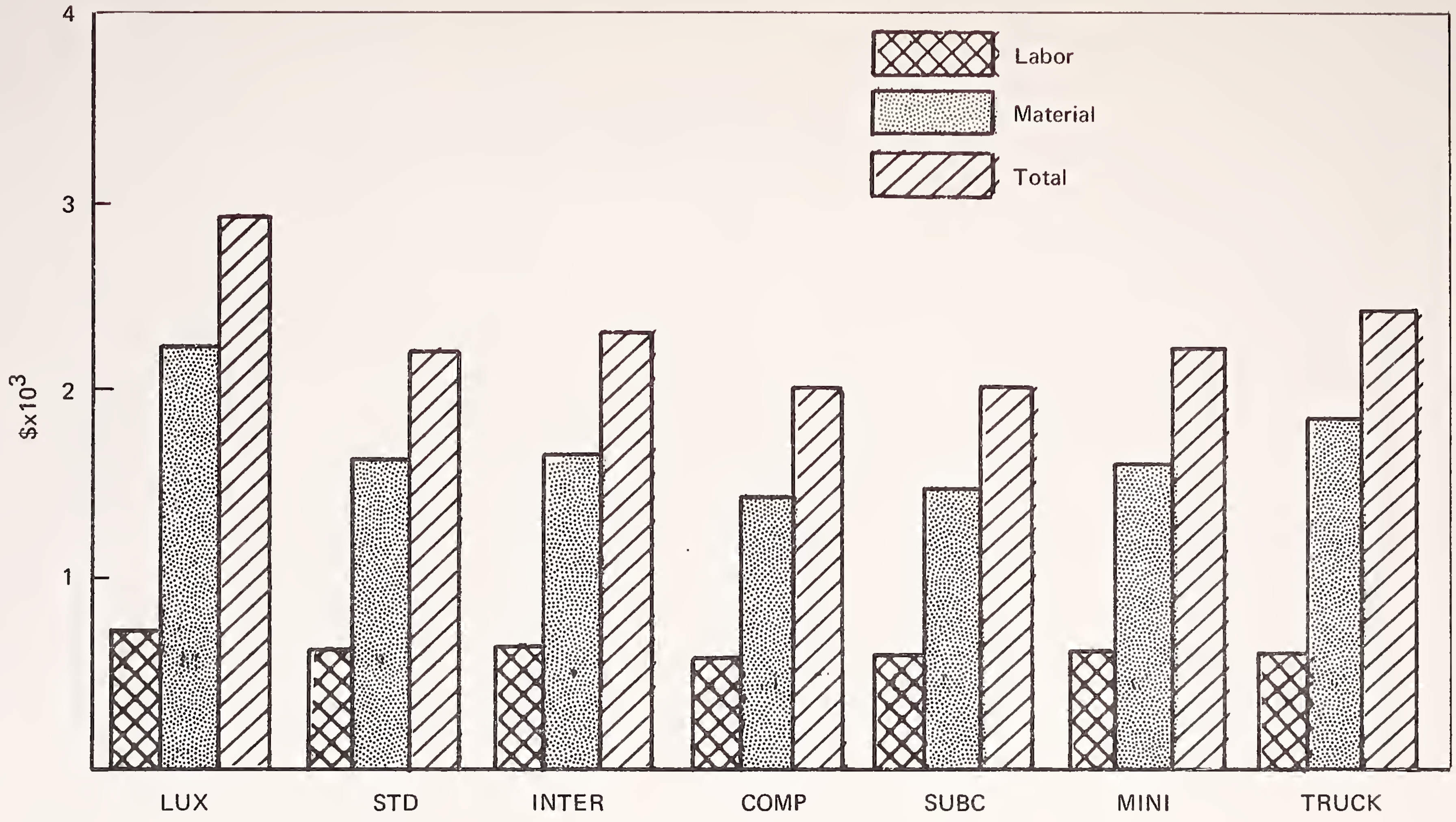

FIGURE 3–4 LIFE CYCLE UNSCHEDULED MAINTENANCE COSTS – AVERAGES – DEALER

TABLE 3-7 UNSCHEDULED MAINTENANCE COST RANKING BODY CLASS COMPARISON

	Material	Labor	Total
Highest	Luxury	Luxury	Luxury
↑	Truck	Intermediate	Truck
	Intermediate	Standard/Mini	Intermediate
	Standard/Mini	Truck	Standard/Mini
↓	Subcompact	Compact	Compact/Subcompact
Lowest	Compact	Subcompact	

/ Means classes are essentially equal.

3.4 COMPARISON BY MANUFACTURER AND MODEL YEAR

Maintenance costs for three vehicles from each manufacturer and model year were averaged by computer resulting in Figures A-103 - A-105. The set of vehicles for Ford and General Motors was made up of a standard, an intermediate, and a compact vehicle each year. Chrysler's set included two standards and an intermediate while AMC was represented by an intermediate a compact, and a subcompact. Table 3-8 lists the specific vehicles used. Figure A-103 shows the life cycle scheduled total maintenance cost by model year and manufacturer. Comparing Ford and GM, which have similar vehicle sets, two conclusions can be drawn; GM scheduled maintenance is in general more costly than that of Ford and that both manufacturers markedly increased their recommended meintenance for two years. In 1972, the regulated emissions standards were made more stringent and at the same time Ford introduced specific maintenance items to be part of their Emission Maintenance. In 1974, GM instituted the maintenance program of Emission Control Service increasing their component of emission maintenance. In the 1974 model year Ford Motor Company instituted an increase in their recommended mileage intervals causing a large decrease in their scheduled maintenance costs. However, in 1975 they reversed the trend for several major items such as changing the oil and replacing the spark plugs and decreased their maintenance intervals. This was offset by a further increase in mileage interval for numerous other items, resulting in a slight net decrease in the 1975 model year scheduled maintenance cost.

In 1975 GM followed Ford's example possibly in response to market pressure and increased all their recommended maintenance intervals; from 6,000 to 7,500 miles, from 12,000 to 15,000 or 12,000 to 22,500 and from 24,000 to 30,000, thereby causing an overall decrease in the life cycle scheduled maintenance cost.

Although Chrysler started specifying Emission Control System Service in 1972, Figure A-103 does not show an accompanying rise in scheduled maintenance costs. AMC is in general lower than the other three manufacturers because of the smaller body class cars used in the example.

Unscheduled life cycle maintenance costs by manufacturer and model year are shown on Figure A-104. The fairly steady level of costs is determined mainly by the common failure rates used for all of the vehicles. Figure A-105 is simply an averaged total of both the scheduled and unscheduled costs.

In order to compare four comparable sets of three vehicles per manufacturer, a second averaging calculation was performed on the revised vehicle list in Table 3-9, the summarized averages are shown on Table 3-10. Figure 3-5 shows the relationship between the various manufacturers and life cycle maintenance costs. General Motors is higher than all others with the exception of the 1975 model year vehicles where Chrysler's recommended

TABLE 3-8 SAMPLE VEHICLES USED FOR COMPUTER AVERAGE COMPARING LIFE CYCLE MAINTENANCE COST

Body Class	Standard	Intermediate	Compact	Subcompact
Manufacturer				
General Motors	Chevrolet Impala	Pontiac Grand Prix	Chevrolet Camaro	-
wt. (lbs.) range	4134-4503	4081-4369	3313-3869	
Ford Motor Co.	Galaxie	Torino	Mustang	-
wt. (lbs.)	3945-4709	3563-4426	2808-3644	
Chrysler	Chrysler Newport Plymouth Fury	Plymouth Satellite	-	-
wt. (lbs.)	4382-4718 4009-4545	3374-4581		
American Motors	-	Matador	Hornet	Gremlin
wt. (lbs.)		3523-4027	2802-3023	2606-2809

TABLE 3-9 VEHICLES IN EACH MANUFACTURER GROUP

	Body Class (Vehicle No.)		
	Standard	Intermediate	Compact
General Motors	Impala (5)	Grand Prix (11)	Camaro (16)
Ford	Galaxie (6)	Torino (12)	Mustang (17)
Chrysler	Newport (7)	Satellite (13)	Valiant (20)
AMC	Ambassador (9)	Matador (14)	Hornet (21)

TABLE 3-10 AVERAGED SCHEDULED MAINTENANCE LIFE CYCLE COSTS

Model Year	1970	1971	1972	1973	1974	1975
General Motors	1297	1297	1312	1565	1526	1057
Ford Motor Co.	781	770	1222	1299	752	699
Chrysler	1188	1189	1167	1127	1140	1223
AMC	-	1015	1051	1083	1013	-

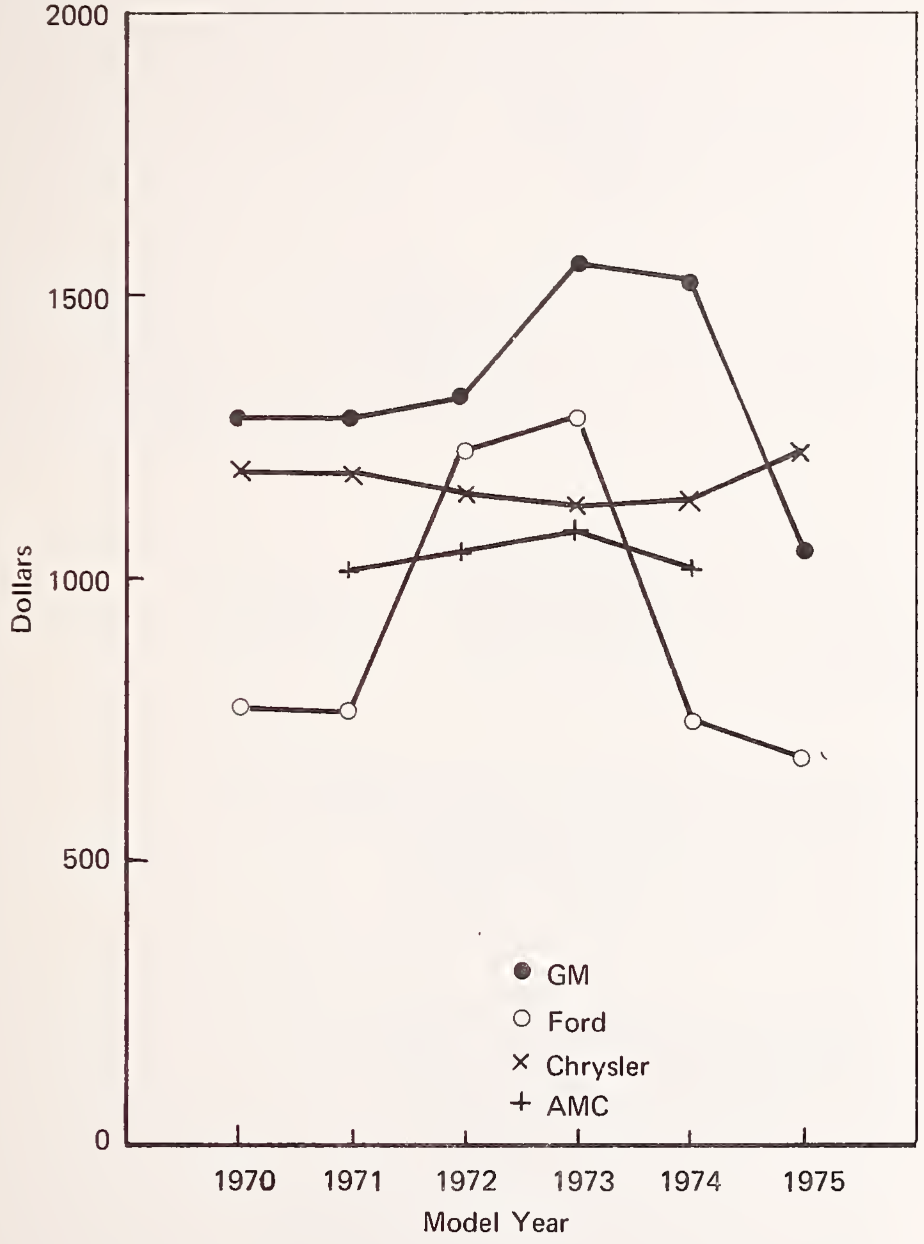

FIGURE 3–5 LIFE CYCLE SCHEDULED MAINTENANCE COSTS BY MANUFACTURER AND MODEL YEAR

maintenance is ~ $164 higher over the vehicle life. Ford's two year jump in 1972 and 1973 made their costs higher than both Chrysler and AMC. It appears, however, that Ford's general recommendations result in the lowest scheduled maintenance costs.

3.5 FACILITY MAINTENANCE COST COMPARISON

All the detailed computer generated graphs used the cost for the maintenance performed at the dealership totally. In reality there are very few vehicles which would not only have all their scheduled maintenance performed but also have it all done at a dealership. In order to determine what the relative cost differences would be for performing life cycle maintenance costs at other facilities, Figure 3-6 was generated from the detailed life cycle total costs calculated from the computer data base, it shows the scheduled maintenance costs at a dealer, an independent repair garage and service stations. Specialty shops were not included as they have only particular capabilities and are not able to perform all the scheduled maintenance. The new car dealer costs are consistently higher than the independent repair garage and the lowest cost are attributed to the service station. The prime reason for this variation is the relative labor rates. These rates based on a national average for 1975 were as follows:

NEW CAR DEALER		SERVICE STATION	INDEPENDENT GARAGE
Domestic Luxury	Domestic Non-Luxury		
$14.00/ Hour	$13.00/ Hour	$9.50/ Hour	$11.00/ Hour

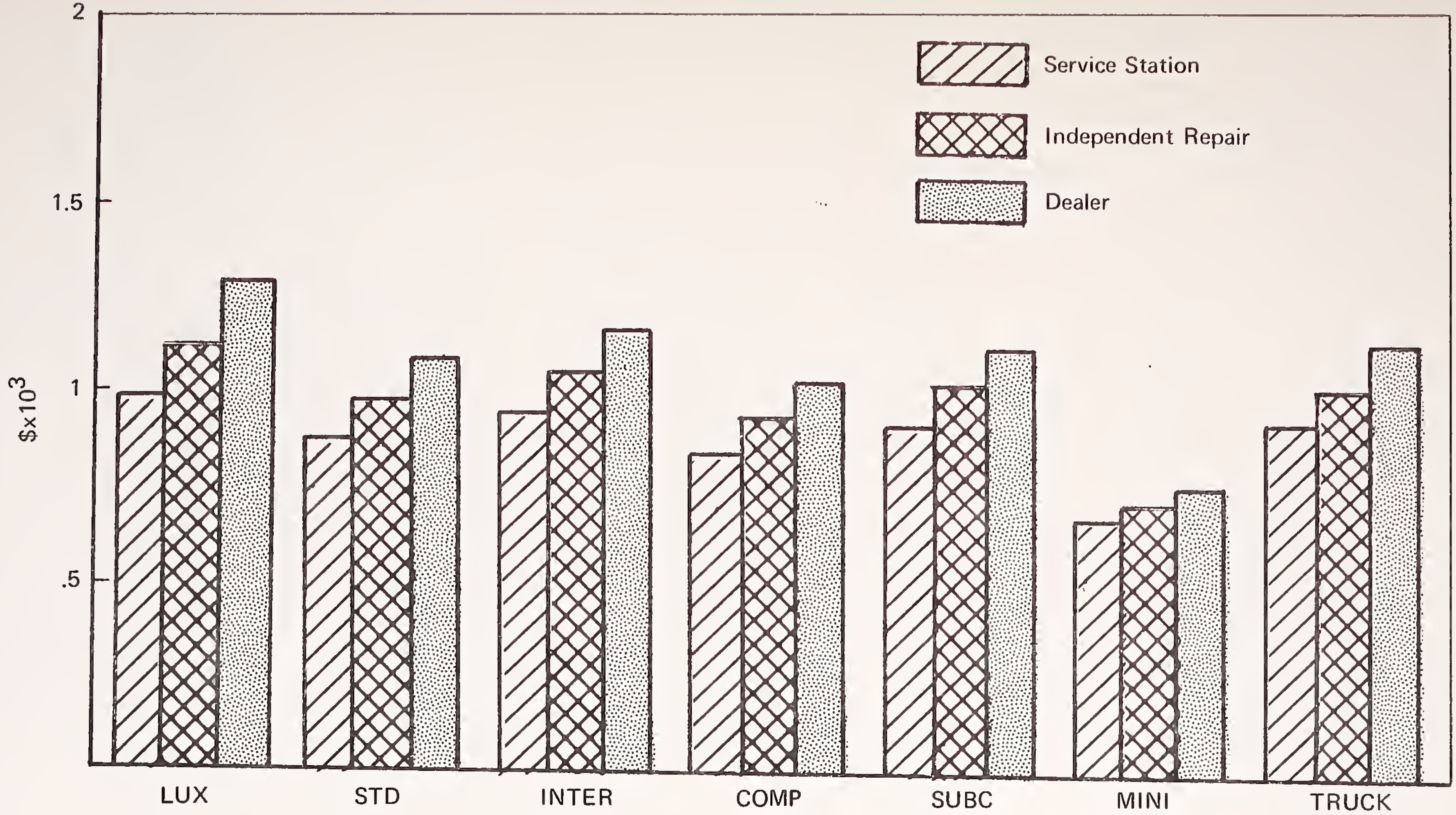

FIGURE 3–6 COMPARISON OF SCHEDULED MAINTENANCE COSTS AT 3 TYPES OF SERVICE FACILITIES

4. FUTURE TRENDS IN MAINTENANCE COSTS, PROCESSES, AND FACILITIES

4.1 INTRODUCTION

Volume I of the companion report* has detailed the maintenance costs, processes, and facilities for the years 1970 through 1975. Between 1975 and 1985 there will be a great deal of technological innovation to meet future goals of improved fuel economy and further reduced emissions. The impact which these technological innovations will have upon vehicle maintenance costs and the service and repair industry is addressed in this chapter.

The specific technological innovations which are addressed in this chapter are:

- radial tires
- lighterweight bodies
    - by design
    - by material substitution
- improved engine/road load matching
- engine modifications involving catalytic converter
    - including fuel injection
- proportional exhaust gas recirculation
- electronic engine components
    - high energy ignition
    - electronic spark control
    - electronic fuel and air control
- lightweight diesel
- stratified charge spark ignition engine
- Stirling cycle engine
- gas turbine
- lockup torque converter and four-speed automatic transmission

The last five innovations are examined as if they could achieve substantial market penetration in the 1980-1985 time period. While this assumption seemed plausible at the time the contract was issued, more recent developments have pushed the introduction date for the Stirling and gas turbine to the 1990 time frame.

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*DOT-TSC-NHTSA-78-25

With the exception of the alternative engines listed, we expect that in most cases the introduction of the new technology will have minimal impact on maintenance costs. Some will require more sophisticated diagnostic equipment such as is currently available for the 1977 General Motors "B" body cars. Most of the innovations, we feel, will result in reduced scheduled maintenance requirements and longer service life. Offsetting these improvements will be a higher replacement cost when and if failure does occur.

In the following sections, the expected service requirements and the impact of those requirements upon the service industry are discussed. Only if the innovation appears to us to be an exception to the general statements of the previous paragraph have we discussed specific impacts upon maintenance requirements. Because of the nature of this chapter, there is no data from which hard conclusions may be drawn. Therefore, we have limited our discussion of impacts to general trends which may increase or decrease repair and service costs.

4.2 RADIAL TIRES

The use of radial tires will not require that any new service facilities or practices be developed. However, because of their higher concentration of tire mass near the circumference, these tires are more susceptible to dynamic imbalance and therefore should be dynamically "spin" balanced. The equipment required for this operation is generally available, although not all service facilities may currently be so equipped.

Tire manufacturers stress that radial tires should be rotated every 5,000 miles in order to optimize their service life. However, the same recommendations are usually made for any type of tire in order to achieve maximum life. There is emphasis on the rotation of radial tires because, we feel, of their increased initial cost which may be substantially offset only by longer life and hence reduced replacement cost/mile, as well as decreased fuel cost.

The costs for rotation and dynamic balancing of any type tire is the same and hence radial tires will cost no more to service and repair than bias-ply tires. However, there may be an increase in costs to the owner of radial tires if he did not dynamically balance and rotate his bias tires, but does so for his radials. In this case, the cost of dynamic balancing (a once per tire cost) is normally twice that of static balancing. The cost for tire rotation is normally about $5 each time. Assuming that radial tires last at least twice as long as bias tires (40,000 miles), there is no increase in total cost for balancing while the cost for rotation will be approximately $40, or about 2/3 the cost of a radial tire. Since rotation will probably not increase the life of a set of tires more than 25% there really will be no significant change in tire replacement costs whether or not the tires are rotated, provided no abnormal wear patterns develop due to wheel alignment faults.

The initial cost of radial tires could exceed the cost of bias ply tires of the same size by a factor of two or more. However, radial tires have an established reputation for lasting at least twice as long as bias ply tires. Therefore, the cost per mile to the car owner will probably be equal to or slightly less for a set of radial than for a set of bias ply tires.

4.3 LIGHTWEIGHT BODIES

There are only two possible means of reducing the weight of automobile bodies: weight conscious design, and substitute materials. Improperly applied and promulgated, both of these techniques, used alone or in concert, would lead to some serious increases in maintenance costs due to increased damageability, material degradation, or specialized repair techniques. There is little likelihood that this will be the case, however. Indeed, it is most probable that the maintenance costs associated with these lightweight bodies will be reduced.

Between now and 1980, the major portion of the weight reduction will be accomplished through more efficient body design - downsizing as epitomized by General Motors' 1977 "full sized B" body cars. It is anticipated that steel body panels will not be made thinner than current production vehicles because to do so would invite dimpling and "oil canning" of the panels. In addition, the marketplace is demanding more durable products and to use thinner than current steel pieces would reduce the corrosion limited life of those components. These steel body components are already being bolstered in their ability to resist rust through the use of galvanizing (one or both sides), electrolytically deposited rust resistant primers, aluminized coatings and other corrosion barriers, emphasized by the automaker's advertising.

The marketplace demand for product durability and the automakers' historically cautious approach to new technologies will ensure that new materials will be utilized only as they have proven themselves. In the pre-1980 time frame, this will not hinder weight reduction progress as much as it may at first seem. From a market standpoint, automotive durability is most epitomized by aesthetics, and the use of new materials in places other than the body panels will be a low risk, high gain proposition for Detroit. As one materials expert notes, "body panels are not the major contributor to vehicle weight. That role is filled by structural members, from fasteners, brackets, and latches to radiator supports, bumper backup beams, and cross members." [1] New materials, notably plastics, are expected to gradually fulfill many of these roles between now and 1980. "Plastic" front end retainers, valence panels, resilient bumpers, inner fender splash shields, various non-structural covers and even loading bearing transmission mounts[1] are being introduced or experiencing a growth in applications for the current and upcoming model year. Where plastics can not fulfill structural requirements, corrosion resistant coated thin section HSLA steel parts are replacing thick, heavy (and rusty) low carbon steel components such as engine mounts. These are all areas where aesthetics are secondary to performance and where the new materials will be sure to stay out of the maintenance cost column.

Long term use of the less exotic but weight saving body panel materials such as aluminum and glass fiber reinforced plastic have demonstrated that these materials do not add to the maintenance costs of vehicles except when entire panels need replacement, and this cost may be more dependent upon the market volume of spare parts than materials dependent. On the other hand, replacement parts costs for some fiberglass panels are comparable to steel panels. Aftermarket suppliers can often sell fiberglass replacements for less than factory steel originals.

For over 20 years there have been production vehicles sold in America which made extensive use of both aluminum and glass fiber reinforced plastics. The latter is known best as the body material for the Chevrolet Corvette, dating back from 1953. Aluminum has been driven on American roads and repaired in American body shops since at least the mid-fifties in the shape of such cars as Austin Healey 100-6's, MGA's, Rover 2000 SC's, 2000 TC's and 3500's, Alfa Romeo GTA's and GTA Jr's., and currently in some Oldsmobiles. At first, all these cars needed special handling and unique repair techniques. Now, however, fiberglass is many times easier to repair than steel (indeed, it is used as an alternate repair material for steel panels) and aluminum, which once required special treatment, can be refinished with most any modern automotive paint. The reputation of aluminum as a body material that can not be straightened and hammered out as can steel is pure myth. This author has repaired crash damaged vehicles made of both materials with comparable ease. In fact, both of these materials are being extensively used for body panels, cabs, and even frames of heavy duty trucks, and this is a market where low maintenance cost is a prerequisite for any new technology.

The lower impact resistance of aluminum and its historical tendency to dimple has caused concern that maintenance costs could be increased due to an increased affinity on the part of aluminum for aesthetically annoying dents and dings. Newly developed alloys such as 6009-T6 and 6010-T6 increase in yield strength to 45,000 and 35,000 psi, respectively, during a typical 400 degree F, 30 minute paint bake cycle. These values are higher than any other body sheet used on automobiles[1] and will improve impact resistance significantly.

Likewise, accelerated galvanic corrosion of aluminum when placed in intimate contact with steel is a factor which may decrease the life of the aluminum at the interface, and hence increase maintenance costs. Welding of such joints utilizing transition material inserts will virtually eliminate galvanic corrosion problems in this type of joint[3]. Another common joining technique which may be corrosion prone is mechanical fastening. This can be overcome through the use of adhesives. There are available modern adhesives which can and do act as sealants. Hence, such bonded joints will not have galvanic corrosion problems because 1) the adhesive will act as a physical barrier preventing metal to metal contact, and 2) water will be kept from the joint by the sealant characteristics of the adhesive[2]. Fastened joints can be similarly protected with a sealant or by the application of an inactive barrier coating or sacrificial metal coating on one or both surfaces to be joined. Galvanized or even aluminized steel can be used successfully in this type of application[2] and will have the added advantage of protecting the steel part as well.

An advantage of aluminum in the area of corrosion is that if proper painting practices are followed, corrosion will not creep under the paint film[2] as it does steel once the paint is chipped or cracked. This characteristic may reduce the need for touch up or panel refinishing.

Fatigue is another issue which is brought up when the durability of alternate materials is addressed. The fatigue life of a specific part made of a given material can only truly be determined by actually testing the part under real world conditions. Indeed, this is one of the reasons why automakers maintain and use their test tracks or proving grounds. This is truly the only definitive method because fatigue life is influenced by many factors[4] including:

- surface defects
- degree of overstressing
- corrosion
- mean stress (algebraic difference between maximum and minimum stresses)

Generalized statements can be made about the relative fatigue life of alternate materials. All conclusions drawn from these statements must be based upon the assumption of proper design practices. For instance, when an alternate material is known to be more resistant to fatigue, use of the new material without design change can be assumed to improve the fatigue limited durability (if any) of the part. Substitution of a material with inferior fatigue resistance without design change may or may not impair durability.

Certainly, if the original material normally failed by fatigue before the useful life of the part was over, use of an inferior material will increase maintenance costs because the part will fail more often. However, if a part's fatigue life normally exceeds that of the car and an inferior (fatigue related) material is used, the durability of that part may or may not be greater than that of the entire vehicle.

Comparisons between the ability of materials to resist fatigue may be made utilizing their fatigue limit.

The fatigue limit is that stress level to which a material may be subjected for an infinite number of cycles without failure. "The most common (test) loading is alternate tension and compression of equal numerical values obtained by rotating a smooth cylindrical specimen while under a bending load[4]."

For comparison, the fatigue limits of several current and candidate materials are presented in Table 4.1(the fatigue limit presented in the Table for HSLA steel is based upon the statement in Mark's Handbooks[4] the HSLA steel often exhibits fatigue limit values in excess of 60% of the tensile strength (provided it is below 200,000 psi). We arbitrarily used 70%, and applied it to the tensile strength of formed GM980X used in a bumper face bar and presented it in Reference 5.

Thus, the 1975-1980 period will be characterized by downsizing and the use of alternate materials in areas where their application is of low risk in terms of consumer confidence. The post 1980 period, on the other hand, will be characterized by tremendous lightweight material substitutions in most areas of the body. The materials that performed well in the pre-1980 period will see extensive use in post-1980 lighweight bodies. General Motors' Manager of Material and Process Engineering, Edwin Ditto, has been quoted[1] as saying that "you will see a car made entirely of fiberglass..with an integral frame and body shell...the avenue to get there is to concentrate on doors, rear decks, hoods, fenders, radiator supports, front headers...those parts that are essentially add-ons now and develop the technology and expertise in making these parts." Ditto was not thinking far out, but was stating the step-by-step technological development process now in use to make a durable lightweight vehicle. As a footnote to his prediction of the all fiberglass car, it should be noted that the Lotus Elan is a car with a body built entirely of fiberglass. The 2-seater Elan could be bought with either a hard top or as an open roadster and had only a centrally located backbone frame around the driveshaft which supported the engine, transmission, front and rear suspensions. The all fiberglass body was entirely self-supporting. This 15-year old design was not too far from Ditto's prediction: the bodies of this sports car have outlasted many of their all steel brethren.

In brief, then, the introduction of lightweight bodies which utilize new dimensions, designs, and materials, will not increase the maintenance costs of future vehicles. Furthermore, improved corrosion and dent resistance of new materials may even reduce maintenance costs.

Footnote: An intriguing and potentially significant finding can result from a brief analysis of the data in Table 4-1.If a particular design in steel is fatigue life limited, there could be a weight increase if aluminum is used for the part and it is redesigned so that the aluminum part will have the same or improved fatigue life. This is illustrated using the average of the fatigue limit values for plain aluminum and carbon steel from Table 4-1 as 13,000 psi and 50,000 psi respectively using the published[4] approximate specific gravities of aluminum and steel as 2.7 and 7.8 respectively. If the steel part has a given unit area and the load is such that the fatigue limit is just exceeded, the unit stress will be approximately 50,000 psi. For comparable fatigue performance, the aluminum must have an appropriate stress of 13,000 psi. The area of the aluminum part must increase by the ratio of 50/13, or 3.8 time the area of the steel. The volume of the aluminum must hence also increase by a factor of 3.8. the weight of the

TABLE 4-1 COMPARATIVE FATIGUE LIMITS OF ALTERNATE MATERIALS

Metal	Tensile Strength KPSC	Fatigue Limit KPSC
Cast Iron	20-50	24-32
Malleable Iron	50	24
Cast Steel	60-80	24-32
Plain Carbon Steel	60-150	24-75
SAE 6150 Heat-Treated	200	80
Cast Aluminum Alloys	18-40	6-11
Wrought Aluminum Alloys	25-70	8-18
HSLA Steels	115*	63*

*Upper limit is an Arthur D. Little estimate based upon Reference 4, 5, and 6; lower limit based on Reference 6

Source: Mark's handbook[4]

part is its unit volume times its density. The steel part of one unit volume will weigh 7.8 units. The aluminum part of comparable fatigue life will weigh 3.8 units times 2.7, or 10.3 units. The aluminum part with comparable fatigue life could be 10.3/7.8 or 1.32 times as heavy as the plain carbon steel part.

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4.4 IMPROVED ENGINE/ROAD LOAD MATCHING

One of the more direct ways to achieve improved fuel economy is to operate the engine at its most efficient point. Since vehicle drivetrains have traditionally been designed for optimum performance (acceleration), instead of fuel economy, it is usually only necessary to run the engine slower than customary at equal power output levels. This may be accomplished with a lower rear axle ratio and/or an overdrive type transmission or a continuously variable transmission (CVT).

Each of these devices will cause the engine to run at slower than "normal" automotive speeds while developing equal power. Presumably, these are abnormal operating conditions not normally expected in the design of the power plant. There is concern, therefore, that the use of lower engine speeds may compromise drivetrain durability due to engine "lugging" and increased working pressures and hence increase maintenance cost.

These operating conditions are not really "abnormal" as they are successfully encountered every day by automotive engines being used for water pumping and marine power plants. Taken to extreme, however, there is no question that low engine speed/high power conditions can be damaging. The pulsed character of the power output of the reciprocating internal combustion engine can lead to the phenomenon known to most drivers as "lugging". This is a severe low speed/high power condition when the individual torque pulses of each of the engine's power strokes can be felt as a sharp jerk which is transmitted through the drivetrain. This is an extreme form of torsional vibration.

Such torsional vibration has been known to be damaging to already highly stressed drivetrain components, particularly hypoid type ring and pinion gears. Intense torsional vibraions can literally cause the oil film between hypoid. ring and pinion gears to be "squeegeed" away and allow metal-to-metal contact. Intense heat is momentarily developed and the gears are sometimes friction welded together. The inertia of the drivetrain and vehicle will break this weld almost as it is formed, of course, leaving behind a rough and annealed spot on the once smooth and hardened gear teeth. Continued extreme torsional vibration can cause a multitude of such spots and lead to eventual failure of one or both gears.

Similar phenomena can occur in the engine. High shock loads on the connecting rod bearings caused by torsional vibration are similar to those caused by detonation and could lead to eventual failure. This was particularly true of those early Porsche engines utilizing anti-friction engine bearings. Lugging of these engines often lead to premature failure.

Fortunately, such extreme torsional vibrations are intolerable to the vehicle's passengers as well as the power plant. Such operating points must be avoided if a car is to be acceptable and therefore marketable.

Lower engine speed will produce some torsional vibration which may or may not be noticeable to the vehicle's occupants. If such vibrations are perceivable, there are currently available torsional vibration dampers and elastic drivetrain mounts which can alleviate such problems. Figure 4-1 is such a torsional vibration damper mounted in the clutch disc of a manual transmission drivetrain. Such dampers are used primarily to improve vehicle driveability. They are not required, however, for vehicle durability. Some Volkswagen models for instance, do not use any torsional dampers and suffer no durability problems as a result.

In order to maintain the required power output at lower rotational speeds, the engine torque output must increase in inverse proportion to the rotational speed decrease. The mean effective pressure in the cylinders and, more significantly, the side reaction force of the piston on the cylinder wall will therefore increase. Provided proper lubrication is maintained and metal temperatures do not exceed those that are "normal" for the particular engine, "....running wear is very little influenced by load or piston speed."[1]

Low speed lubrication is, however, thought by some to be a potential problem. As engine speed decreases, so does the output of the engine's oil pump and hence the supply of oil to the connecting rod bearings. Oil is normally splashed or thrown up onto the cylinder walls as it squirts out from around the rod bearings. In some cases, drilled oil holes run through the length of the connecting rod and oil is actually squirted directly onto the cylinder wall from small holes in the rod. Inasmuch as any increase in piston cylinder clearances resulting from wear will indeed cause less oil to be squeegeed off of the walls, any increase in wear caused by low speed operation could be self-limiting. "The wear tends to decrease with increased mileage (often initial indications of wear, such as greater oil consumption taking place), this being probably due to the larger amount of oil passing the pistons."[1]

Modern lubrication systems are adequately designed for low speed running. Modern American engines, as used in contemporary passenger cars, are already running at very low rotational speeds, (rear axle ratios as low as 2.45 to 1 are not uncommon) and engine speeds significantly lower than is current practice in urban conditions will result in acceptability problems from the standpoint of torsional vibration. The fuel economy gains to be made with this low engine speed concept will therefore logically occur in suburban or highway driving where the engines speed can be reduced to those now typical of urban driving. There are many studies which indicate that the useful life of modern vehicles is 100,000 miles or more, and estimates are that most of this occurs in urban situations. (Hence the EPA composite fuel economy figures include 55% "urban" and only 45% "highway" driving). It is a reasonable assumption, then, that the lubrication systems of modern engines are equal to the task of low speed lubrication of both the cylinder walls and bearings. Modern engines spend a majority of their life at low speeds and survive. A decrease in highway engine speed to current urban

Source: Arthur D. Little, Inc.

FIGURE 4-1. TORSIONALLY DAMPED CLUTCH

engine speeds will not cause any changes in engine life due to poorer lubrication and higher cylinder wall reaction loading.

High mean effective pressures experienced at low speeds are thought to cause premature exhaust valve failure. Problems with exhaust valves have, over the years, been experienced by many motorists when they have used the family car for heavy hauling such as pulling trailers while on vacation. The assumption has been made that the high loads were the direct cause of the valve failure (burned exhaust valves). This assumption, backed by years of "experience", is none the less incorrect.

High loads at low speed are not a direct cause of exhaust valve failure. High valve temperatures are a cause of burned valves, but high loads at low speed do not inherently cause valve temperatures extreme enough to cause burning or failure. Petersen's Automotive Troubleshooting and Repair Manual[2] and Audels' New Automobile Guide[3] indicate that burned valves are caused by:

a) close tappet clearance

b) eccentric valve face or seat

c) deposits on valve or seat face

d) improper seat width

e) warped valves

f) improper block (head) cooling

g) improper guide clearance

h) improper spark timing (advanced)

All of these factors except the last affect the heat transfer away from the valve through the seat or guides or lead to other factors which affect heat transfer from the valve. Spark timing which is too far advanced can lead to detonation which causes temperatures extreme enough to burn not only the valves but the pistons as well. Ignition timing and preprogrammed advance curves which are adequate for high speed operation may be too far advanced for low speed conditions and may have to be retarded in order to avoid detonation in this case. The motorists who experienced valve burning during high load, low speed operation were either finishing off an incipient valve failure or were operating with improper ignition timing or were generating such high effective compression ratios to cause detonation.

Low speed, high load conditions are characterized by throttle positions approaching wide open operation. Under these conditions the volumetric efficiency of the engine is high and the cylinders are filling much more completely than at lesser throttle openings and/or higher speeds (this is a fundamental reason for the improved fuel economy). The effective compression ratio is therefore higher under these operating conditions. It is often times improperly assumed that these higher compression ratios result in higher valve temperatures. However, "an increase in the compression ratio, as a rule, lowers the valve temperature, but if the compression is carried too high and detonation sets in, the effect is reversed."[4]

It was shown above that valve burning is caused by inadequate transfer of heat away from the valve through the seat and/or guide. Low speed operation increases the amount of time that a valve is closed and hence the time available for heat transfer from the valve head to the valve seat. Provided that there are no existing problems such as deposits on the seat which interfere with this heat transfer, low speed operation should not reduce valve life as it actually increases the time available for valve cooling.

Fuel conservation techniques which lower engine speeds and increase engine operating pressures will not inherently cause premature engine failure and hence increase maintenance costs provided that there is adequate lubrication and detonation does not occur. The lubrication systems of modern engines are adequate for the task. Ignition systems may have to have their advance characteristics altered to accommodate the new operating conditions. Automotive engines can run reliably under high load, low speed conditions in automobiles just as they do in water pumping and marine applications.

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4.5 CATALYTIC CONVERTERS AND FUEL INJECTION EQUIPMENT

The use of catalytic converters of any kind primarily affects the air/fuel ratio at which the engine is run. Other, secondary engine modifications, if any, are usually employed in order to allow the engine to operate in an acceptable manner at the air/fuel ratio range which is demanded by the catalytic converter. When first introduced, catalytic converters were designed to reduce only emissions of carbon monoxide and unburned hydrocarbons. To assure an adequate supply of oxygen for these oxidation processes to take place, engines using these converters generally required air/fuel ratios which were slighly leaner than stoichiometric.

While slightly lean operation is a departure from pre-emission standard automotive practice, the introduction of catalysts actually resulted in the use of richer air/fuel ratios than was the practice with pre-catalytic emission controlled cars. These pre-catalyst cars ran on very lean air/fuel ratios in order to assure complete combustion of the fuel and thereby assure low emission rates of carbon monoxide and hydrocarbons. It is a well known fact that operation at too lean air/fuel ratios with conventional ignition systems and other engine components can cause problems ranging from misfiring, after-run, and driveability problems - all annoyances - to burned pistons and valves - serious, costly problems. Such problems can and were overcome by the introduction of higher engine operating temperatures, more expensive transistor switch type, electronic ignition systems and the use of more exotic materials in engine valves. The use of somewhat richer air/fuel ratios (but still leaner than stoichiometric) with catalysts actually reduced or eliminated some of these problems caused by overly lean engine operation.

The three-way catalysts which are just being introduced, require engine operation at air/fuel ratios which are only slightly richer than stoichiometric and within a very narrow band. Thus, engine operation and durability should, in general, return to that expected of pre-emission controlled engines. At the very least, "vehicles equipped with the reduction (three-way) catalyst system should not be more susceptible to engine malfunctions such as fuel runouts, misfires, and ignition failures than (then) currently available 1975 vehicles equipped with oxidation, catalysts in the post manifold position."[1]

However, conventional carburetion systems can not maintain air/fuel ratios at the required point precisely enough to allow three-way catalyst systems to operate. More sophisticated engine carburetion systems are required.

These more sophisticated systems will take the form of electronically controlled carburetors or electronically controlled mechanical fuel injection systems. While differing in their principle of operation, these units have one thing in common. They both require a feedback control loop which continuously adjusts the air/fuel ratio according to the amount of oxygen present in the exhaust gas ahead of the catalysts.

These feedback unit systems all use an oxygen sensor mounted in the exhaust system. Estimates are that these sensors will last only 25,000 to 50,000 miles[2,3] and will cost between \$30 and \$60[3].

The impact on the vehicular maintenance costs of fuel injection has been reasonably well established by history. Systems of this generic type have been around since the 1957 Corvette line offered mechanical fuel injection systems. Modern electronic systems have been in high volume use since Bosch introduced its electronic fuel injection system in the late 1960's. The closed loop control systems are a combination of electronic control with mechanical injection. Such systems offer precise control of air/fuel ratio and require virtually no periodic maintenance. When a fault occurs, however, it requires a competent, trained service technician to diagnose and repair the problem. These systems offer the advantage of being virtually free from periodic adjustments and tuning. The trade-off comes through when parts need replacement, the cost is several times higher than with conventional, carbureted systems. Typical over the counter prices for Bosch or Roosa Master (Oldsmobile) fuel injectors are \$30 to \$50 each, while the electronic "block box" costs \$150 to \$250. A typical carburetor, for comparison's sake, costs \$30 to \$100.

The Carter Carburetor Division has recently developed an electronic carburetor for use with three-way catalysis systems. Because this is a modification of their conventional carburetors rather than a totally new system, the reliability and durability of the system, while as yet unproven, can be reasonably assumed to equal that of the present day carburetor. It can also be assumed that service personnel with specialized training will be required to service and repair the electronic circuitry and the same oxygen sensor as fuel injection systems.

Thus it can be expected that the use of catalysts in general will alleviate some of the engine problems brought on by pre-catalyst emission control technology. However, three-way catalysts will be accompanied by more sophisticated fuel delivery systems which will require frequent, periodic replacement of a relatively expensive sensor, and which have components which may have a longer useful life than current carburetor systems, but which will cost more to replace when failure does occur, and which will require mechanics of a higher skill level for diagnosis and repair.

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4.6 EXHAUST GAS RECIRCULATION

With the advent of the 1975 model year, most cars have been and will be equipped with exhaust gas recirculation (EGR). The technology involved in this recirculation system itself consists of a vacuum operated poppet type valve with various vacuum control devices. As such, this technology involves nothing new to the automotive industry. Vacuum motors have been used on heaters and air conditioners for over a decade, and vacuum controlled ignition advance has been used for almost two score years. This fact, coupled with the legal requirement of 50,000 mile durability makes it inconceivable that the EGR systems themselves should significantly impact the maintenance costs of a vehicle.

What is not so clear are the possible side effects of the EGR on other parts of the engine. As yet, there is insufficient data available to draw definite conclusions. It is quite possible, however, that the use of EGR could lead to excessive buildup of intake system deposits and increased sludge buildup in the crankcase, rocker arms, and oil ways[1]. Since exhaust gasses contain water and trace amounts of sulfur oxides, there is a chance that corrosion of the induction system, intake valves, and even piston crowns could occur from the action of sulfuric acid under certain short trip, stop and go type driving. Even without EGR, such corrosion does occur and can be severe if not catastrophic as anyone who has stored a car for a long period of time can attest. While substantiating data is not yet available, it is our opinion that the use of EGR can not help but exacerbate these potential problems.

All these side effects of EGR are cumulative and can be expected to cause problems, after a long period of engine operation. Since most cars are scrapped at approximately 100,000 miles and/or after they have been in used approximately ten years, the problems caused by EGR can be expected to decrease the useful life of the vehicle rather than to increase minimum costs. We say this because we feel that most owners would choose to trade in, sell or scrap an old, high mileage car rather than pay to have substantial engine work performed. In general, old, high mileage vehicles not in good running order are scrapped rather than rebuilt.

The use of EGR, then may be expected to shorten the useful life of the vehicle. This may occur not because of a failure in the EGR system itself, but because of possible side effects resulting from the circulation of the products of combustion through the intake system.

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4.7 HIGH ENERGY IGNITION SYSTEMS

Popularly known as "electronic ignition" systems, high energy ignition systems will not alter the life cycle miantenance costs of a typical car. While these systems eliminate the need for replacement of points and condensers and extend the life of spark plugs, they also decrease the life of distributor caps, rotary and ignition wires. Thus, the savings on points, condensers, and spark plug replacements are offset by the more frequent replacement of other ignition components.

An examination of General Motors' scheduled maintenance for the years 1973 and 1977 indicate that the replacement mileage for spark plugs has doubled with the advent of GM's high energy ignition system. For 1973 cars the replacement interval is 12,000 miles while for 1977 cars it is 22,500.

On the other hand, for 1973 there is no mention of a scheduled maintenance item for spark plug wires. For 1977, however, General Motors explicitly states that spark plug wires must be checked every 15,000 miles. With electronic ignitions, spark plug wires must be examined more frequently than spark plugs need replacement. Indeed, aftermarket forecasters are predicting a 15% annual growth rate for ignition wire sets, where as the "sales of spark plugs are expected to dwindle,"[1]

Electronic ignition systems are not expected to have any impact upon the service industry in terms of mechanic skills, facilities required, or diagnostic tools. These ignition systems are "black box" components. Replacement of individual items is generally not possible. The system either works or it does not. If if is does not, the mechanic must replace the black box, the coil, or the sensors. A review of the troubleshooting procedures for the systems used by Ford, General Motors, Chrysler, American Motors, and International Harvester indicate that the tools currently available in any well equipped establishment are all that is required to diagnose these systems. Typical tools include a volt-ohmeter, wire, and insulated pliers. The AMC and HI systems also require a "testor" device. This device is simply a low cost "black box" which performs a simple switching function to help isolate trouble either in the ignition systems' black box or the sensor. Purchase of these testors is not considered to be a significant expenditure having any impact upon the repair and service industry.

Thus the use of high energy ignition systems will alter the maintenance required on cars, but will have no measurable impact on the owner's maintenance costs or the repair and service industry.

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4.8 ELECTRONIC CONTROL SYSTEMS

Ever more stringent emission control systems require more and more precise control of engine operational parameters such as spark intensity, spark timing, and air/fuel ratio. Increasing emphasis on automotive weight reduction and a desire for simpler wiring systems has kindled ideas for the elimination of discrete electrical system components connected by over 400 yards of wire in favor of multiplexed electronic systems in which one device may perform tasks currently done by several. All of this requires the use of relatively sophisticated electronic microprocessors on board the vehicle.

There is concern that the use of such microprocessors may increase service and maintenance costs. If replacement costs only are considered, it is quite probable that this concern is justified. A quick review of any aftermarket parts catalogue will reveal that replacement costs for electronic ignition components, for example, are significantly higher than replacement costs for the components of conventional ignition parts. However, the replacement frequency of electronic components, and the components with which they interface, may exceed that of conventional systems several fold, yielding a net reduction in life cycle costs.

When they first appeared, electronic systems suffered from a relatively short life due to extreme automotive environmental conditions. Sophisticated electronic components were placed (and some still are) in the passenger compartments to avoid severe under-the-hood temperatures.

Limited component life due to problems peculiar to the automotive environment are being overcome, however. More and more components are being located within the engine compartment and even right on top of the engine, as with General Motors' distributor mounted high energy ignition system. When fully developed, we feel that the future automotive electronic components should be just as reliable as today's solid state automotive radios and entertainment systems.

In some cases, electronic control of parameters previously fixed, such as air/fuel ratio, will require diagnostic equipment and commensurate mechanic skill levels which are more sophisticated than may be presently available in order to assure cost effective diagnosis and repair. This may in turn increase the cost of repair and service operations. However, we expect that the increased service life of these components will offset the increased repair and service costs and yield a net reduction in maintenance costs.

4.9 AUTOMOTIVE DIESEL ENGINE

The longevity of modern diesel engines used in industrial, marine, and heavy duty truck applications is well know. This excellent service life with low maintenance costs is due to many factors including the following.

- lubricity of fuel
- minimal engine "off" time
- more robust design

It is not obvious that the absence of the latter two factors in the application of the diesel engine to automotive (passenger car) usage will allow comparable durability and low maintenance costs of automotive diesels.

Most passenger car trips are less than ten miles in length[1]. This type of service allows the buildup of condensation in the crankcase because of piston blow-by and because the oil rarely reaches temperatures high enough to drive off the condensate. Consequently, relatively frequent oil changes are required in this type of service in order to keep the water content of the engine lubricant at acceptable levels.

The oils designed for passenger car, spark ignition engines (grades SA through SE) contain additives which inhibit the corrosion which could be caused by the condensation, whereas oils formulated exclusively for use in diesel engines (grades CA through CD) do not contain the corrosion inhibiting additives. This is because the diesels traditionally run for long periods of time and at temperatures high enough to prevent significant accumulations of condensate. However, the grade "C" oils are capable of withstanding the diesel's higher temperature and load extremes for many more hours of operation than current "S" grade oils.

The net result is that, with presently available lubricants designed for either continuous heavy duty diesel use ("C") grade or intermittent, lower temperature and loading use ("S" grade) high quality "S" grade engine oils must be used in passenger car diesels to fight corrosion caused by intermittent service. This oil will not stand up to the other diesel operating conditions as well as "diesel engine" oils and hence must be changed more frequently than in most spark ignition engines. Consequently, most manufacturers of diesel powered passenger cars recommend oil and filter change mileage intervals which are roughly one-half of their recommended intervals for their gasoline engines. Recently a grade S-C classification has been developed for automotive diesels. However, this has not resulted in a change in oil change policy.

The fact that diesels have in the past been more ruggedly constructed than gasoline engines does not necessarily mean that the new passenger car diesels, which are derived from spark ignition engines, will have durability which is inferior to modern passenger car power plants. Volkswagen, in fact, found that above 4500 rpm, the inertia forces on their four cylinder Rabbit power plant exceeded the forces generated by the cylinder gas pressure in either the gasoline or naturally aspirated diesel version. Since that particular engine was designed to be capable of running at speeds above 4500 rpm, whether the engine is a gasoline or naturally aspirated diesel engine makes little difference to its durability from a loading standpoint. It is reasonable to conclude, therefore, that dieselization of existing gasoline engines should not, in and of itself, reduce the durability of the engine, provided that the gasoline engine is reasonably durable in the upper speed ranges (4000-6000 rpm).

The increased cost of more frequent oil changes should be more than offset by a reduction in other normal maintenance procedures and replacement parts costs. For instance, a comparison of the flat rate labor times required to tune up a light duty Dodge truck with a gasoline engine and with a Perkins diesel engine are shown below.

Dodge Truck Tuneup Times[2]

Gasoline Engine Tuneup — 2.6-4.4 Hours Depending upon Model

Includes renew spark plugs, R&R distribution, renew points and condenser; adjust ignition timing, carburetor, and belts; check and clean battery terminals, service air cleaner; check coil, service manifold heat control valve, clean fuel pump sediment bowl and replace or clean fuel filters, renew PCV valve.

Perkins Diesel Engine Tuneup — 3.0-4.2 Hours, all Models Depending Upon Number of Injectors Adjusted

Check and clean battery terminals, check starter motor current draw, clean and renew air cleaner, R&R injectors and test, adjust injectors as required.

For the gasoline engine, of course, the cost of the new spark plugs, points, condenser and possible wires, distributor cap, and rotor, must be added to the labor charge.

The tuneup on a diesel engine is at most, comparable in cost to that of a spark ignition engine in the same vehicle.

Other items which may add to the total maintenance costs of the diesel powered passenger car are normal replacement of the heavier duty battery required, as well as possible replacement of the heavier duty starter motor and charging systems usually associated with diesel engines.

The costs for replacement of diesel fuel injection components appears comparable to the costs of equivalent gasoline fuel injection equipment[5].

Perhaps the biggest problem to be overcome with the introduction of diesel passenger cars is the training of service personnel. The diesel engine operates on a markedly different principle than gasoline engines. While it may actually be simpler, the diesel power plant appears foreign to the mechanic familiar only with the spark ignition engine. A completely new set of diagnostic procedures is required by the diesel engine. Figures 4-2 and 4-3 compare the basic diagnostic procedure carried out for diesel and spark ignition engines. These figures are presented in order to illustrate the markedly different diagnostic procedures which are used.

It should be apparent from Figures 4-2 and 4-3, however, that the same equipment types are required for both engines. With the diesel engine ignition service equipment of the spark ignition engine is replaced by a set of high pressure gages to test the fuel injection system. The cost for the gages should be approximately the same as the cost of high quality hand held ignition service gages.

It is reasonable to conclude that the introduction of the diesel engine to the passenger car fleet will have the greatest impact upon mechanic training. The cost of tools and equipment as well as the lifetime maintenance costs of the diesel will be, at worst, comparable to the present spark ignition engine. The elimination of peridoically replaced ignition system components (spark plugs, spark plug wires, distributor caps and rotors, points and condenser) may actually result in a net reduction in both the total cost of replacement parts and, depending upon tuneup intervals, service labor as well.

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5. Based upon over the counter prices for Bosch (Volvo) gasoline fuel injectors and Roosa-Master (Oldsmobile) diesel fuel injectors

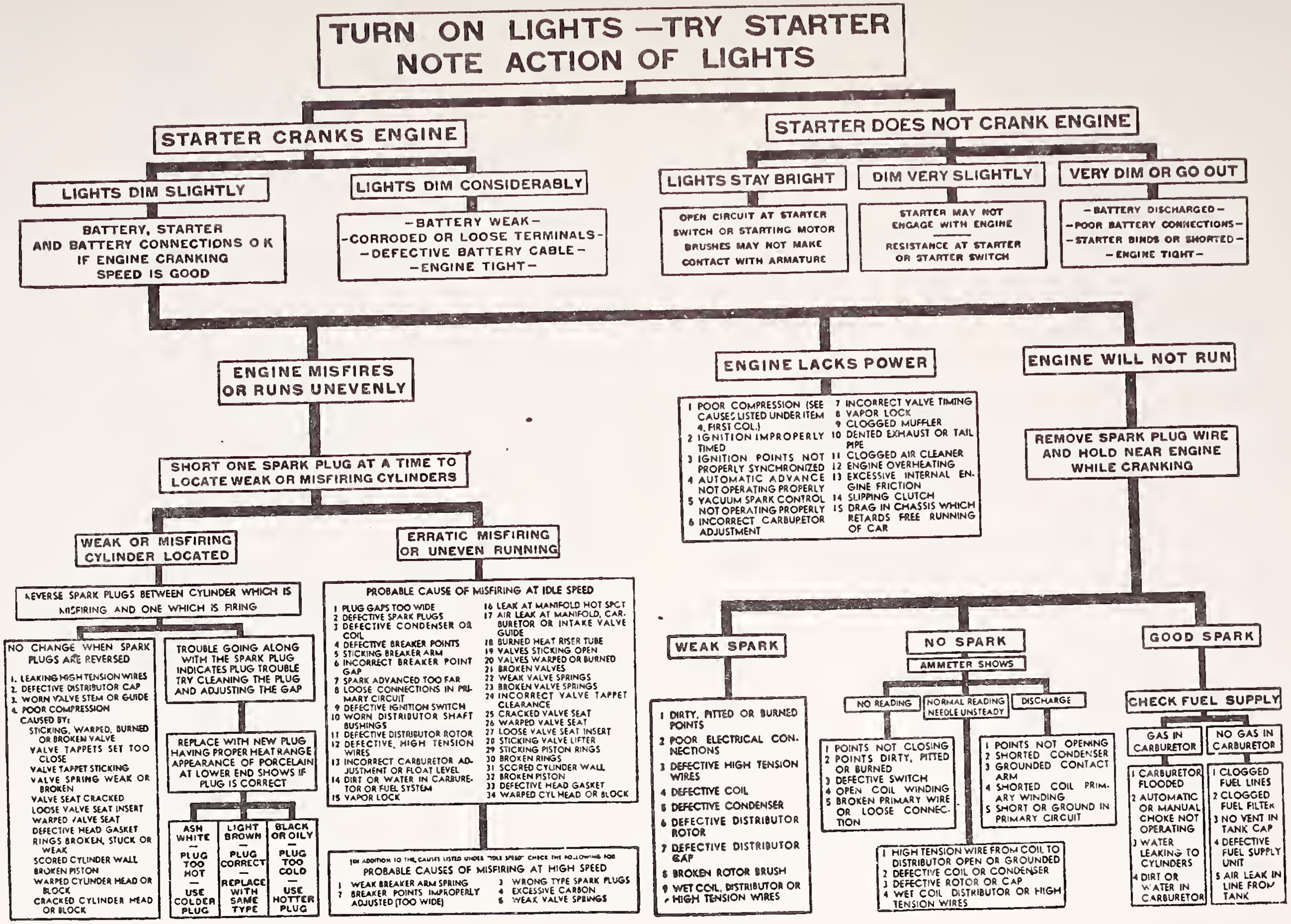


FIGURE 4–2 GASOLINE ENGINE TROUBLESHOOTING CHART

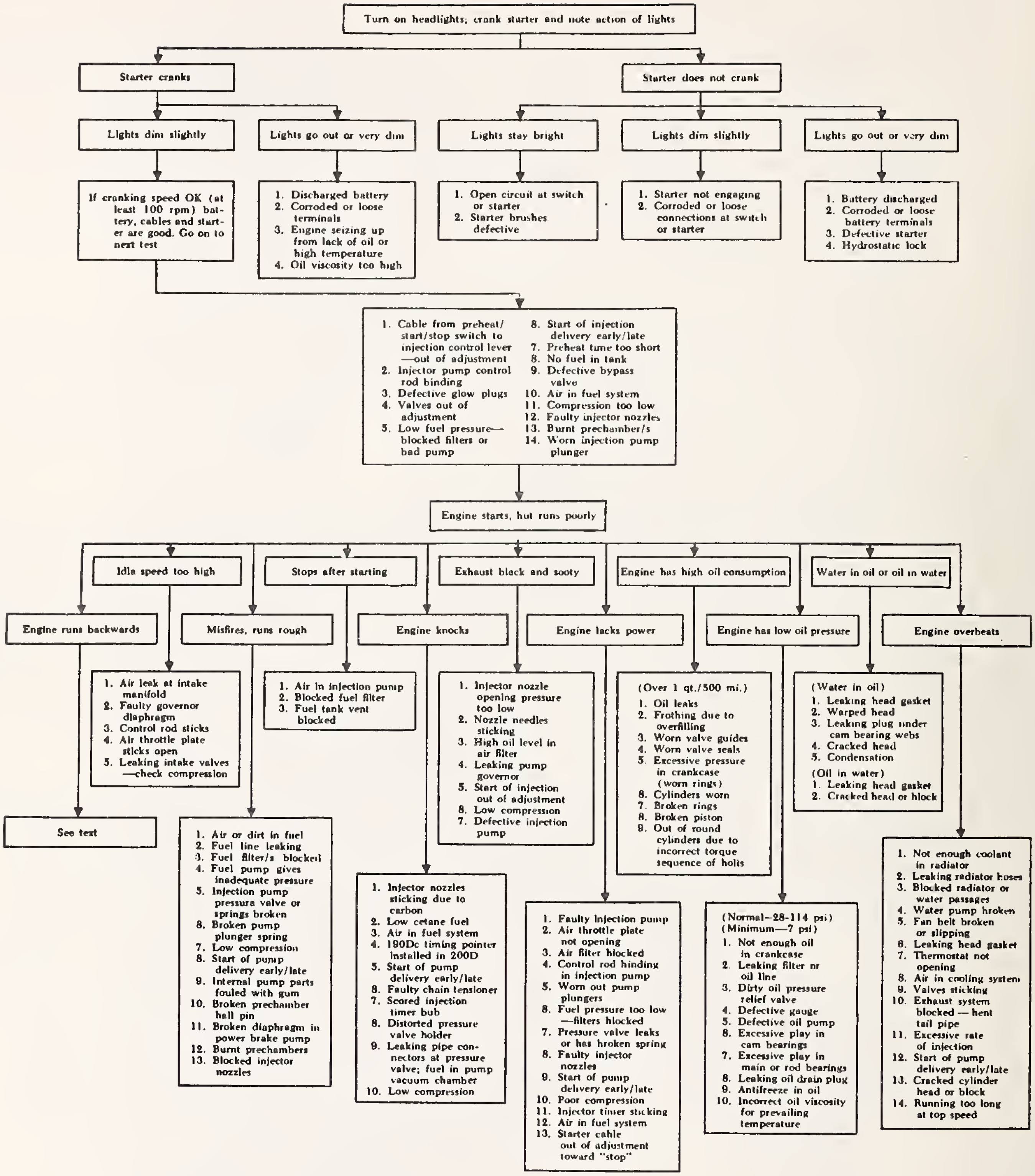


FIGURE 4-3. DIESEL ENGINE TROUBLESHOOTING CHART

4.10 STRATIFIED CHARGE ENGINES

A stratified charge engine, for the purposes of this study, is defined as an Otto cycle, gasoline fueled, spark ignition engine which runs on a heterogenous mixture of fuel and air. The mixture is purposely fuel rich in the region of the spark and lean at some distance from the spark. The rich mixture is the easier to ignite and serves as the ignition source for the lean mixture. A properly designed stratified charge engine is fuel efficient due to an overall lean mixture of fuel and air, and produces lower nitrogen oxide emissions than non-stratified charge engines.

There are two ways of achieving a controlled stratified charge within an engine's cylinders:

- multiple intake valves with multiple carburetor circuits (Figure 4-4)
- direct fuel injection designed to achieve stratified fuel distribution

The multiple valve system is currently in use by both Honda and Mitsubishi, while the direct fuel injection systems are still under development by companies such as Ford (Proco engine) and Texaco.

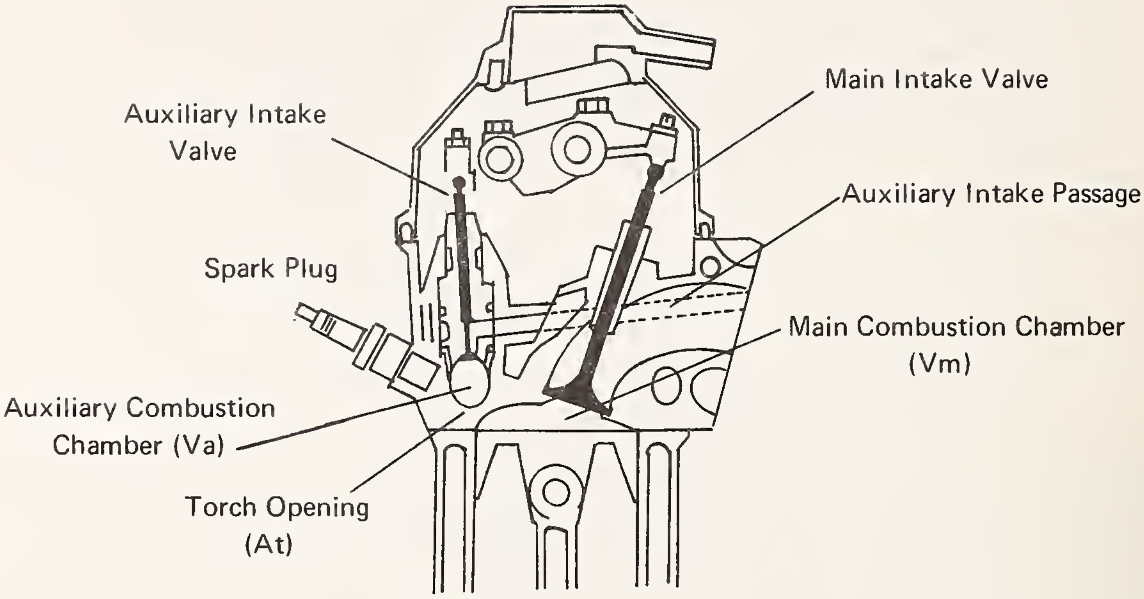
4.10.1 Multiple Valve Type

From a repair and maintenance standpoint, the multiple valve system is a relatively inexpensive and simple evolutionary change to the conventional Otto cycle engine having minimal impact on maintenance costs, procedures, or facility requirements. Engines utilizing this system differ from conventional engines only to the extent that they have three valves per cylinder instead of the usual two, an additional carburetor and manifold circuit. This system would then impact only:

- Cost of adjusting valves - increase by less than 30%
- Cost of grinding valves (valve job) increased by approximately 25%
- Cost of a replacement carburetor - increased by approximately 30-50%

These projected impacts are based upon a study of the flat rate time published for valve work. Valve adjustment times are an almost direct function of the number of valves to be adjusted with a fixed time for removing and re-installing the valve cover, regardless of the number of valves.

The time that is needed to grind valves is also a direct function of the number of valves to be ground. However, this work requires removal of the cylinder head which takes about as much time as the actual grinding operation on a conventional six cylinder engine. Therefore, it is estimated that removal and replacement of the cylinder head takes about one-half of the total time, and valve grinding takes the other one-half of the total job. One additional valve per cylinder will increase the total valve grinding time by 50%, or the total job time by about 25%.



Source: *Asanuma, Babu, & Yagi; Modeling and Evaluation of Combustion Process of a Three Valve Stratified Charge Engine.* Presented at the Fourth International Symposium on Automotive Propulsion Systems.

FIGURE 4–4 TYPICAL MULTIPLE INLET VALVE STRATIFIED CHARGE ENGINE

A study of the flat rate manual indicates that carburetor work - either tuning, removing or rebuilding is relatively insensitive to the number of separate circuits or venturis in the carburetor. Hence, no increased costs are associated with the maintenance of the carburetor on this type of stratified charge engine.

Parts prices published in the flat rate manuals for replacement carburetors appear to have a very loose correlation with the number of venturis or circuits. A two venturi carburetor costs the vehicle owner about 30% more than a single venturi carburetor, while a four venturi unit costs about 50% more than a two venturi carburetor.

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4.10.2 Direct Injected Type

The direct injected stratified charge engine utilizes a fuel injection system very similar to the systems used on diesel engines. Indeed, the fuel injection maintenance requirements, facilities, and procedures would be identical to those covered in the diesel engine and catalytic converter (fuel injection) sections of this report. In addition, however, this type of stratified charge retains the Otto cycle's spark plugs and ignition systems maintenance requirements.

The use of direct injection stratified charge engines, then, will increase the required skill level of mechanics as well as the complexity and type of diagnostic equipment needed. The impact of these engines upon the repair and service industry facilities, procedures and skill levels will be the same as that of conventional engines which have been fitted with fuel injection.

The use of either type of stratified charge engine appears to have no adverse effect upon engine life.

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4.11 STIRLING ENGINE

The Stirling engine is being developed as a reciprocating piston, closed cycle, continuous combustion power plant using hydrogen as the working fluid. The pistons transmit their motion to the engines output shaft via either a conventional connecting rod and crankshaft or a swashplate.

With the exception of the piston and swashplate or crankshaft, these engines represent completely new technology and will undoubtedly require an entirely new set of maintenance processes and facilities. By the time that the Stirling engine is on the road, however, we project that its maintenance costs would be approximately of the same order as conventional Otto cycle engines.

The new maintenance processes and facilities would be required to service the following Stirling engine characteristics:

- High pressure (up to 200 atmospheres hydrogen working fluid)
- Advanced technology seals requiring extreme cleanliness and close tolerance assembly
- Recharge hydrogen supply at least once per year[1]
- Continuous combustion systems
- Complex load and speed control system which influences not only combustion but engine cycle as well

At the present time it is not possible to specifically predict the exact facilities and procedures required. It is clear, however, that mechanics must be trained in new skills and new standards of cleanliness and mechanical tolerances. Some means for safe, high pressure recharging must be developed to annually renew the working fluid which unavoidably escapes around the engine's seals and even through the engine block. This requires not only on site, high pressure recharge equipment, but a mass distribution system for the hydrogen working fluid as well.

Fortunately, the Stirling engine will not adversely impact other vehicle systems. Current projections are that a production Stirling engine can be coupled to present transmissions and that the size and weight of the engine will be comparable to current diesels of equivalent power[1,2]. Thus, no substative changes will be required of vehicle drivetrains or suspensions.

The Stirling engine does have some maintenance attributes which will clearly decrease some of the maintenance costs of conventional engines. These attributes are a result of:

- closed cycle operation
- continuous combustion external to the engine
- completely sealed engine

The closed cycle operation of the engine ensures that no airborne dirt or other contaminants are drawn into the engine where they could damage moving parts. This assures maximum life of the pistons, bearings, and other engine components since dirt is the single greatest cause of mechanical failure in most properly designed equipment.

The continuous combustion system external to the engine assures relatively even temperatures throughout the hot parts of the engine, minimizing the carbonaceous deposits and formation of partially burned, corrosive combustion products usually associated with intermittent or instantaneous combustion systems such as those of Otto or Diesel engines. Also, because the combustion takes place in an area physically separate from the moving parts of the engine, there is no contamination of the engine lubricants or deposition of harmful materials on pistons and valves. It is for this reason that many are projecting engine durability at least equal to current diesel engines[2,3] and an absolute elimination of the need for periodic oil changes[2].

The working fluid in the engine is very tightly sealed in the power producing areas (swept and clearance volume) of the engine. Because high pressures (up to 250 atmospheres) must be maintained for long period of time, every effort is made to seal the working fluid in the volume above the pistons. Extreme care is taken to provide a tight seal between the pistons and the crankcase. This efficient seal, by its very nature, also serves to keep the lubricating oil from the working fluid. Hence a Stirling engine will consume virtually no lubricating oil during its normal lifetime[2].

It appears, then, that the Stirling engine will require completely new mechanics' skills and facilities for its maintenance and repair, but that its need for periodic maintenance will be much reduced from today's engines. It also appears as if the Stirling engine may actually outlive its conventional Otto cycle engine as it is potentially at least as durable as modern diesel engines.

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4.12 GAS TURBINE ENGINE

In its current form, the gas turbine engine offers many maintenance advantages over state-of-the-art reciprocating engines. Because they utilize continuous combustion, a sealed lubrication system, and their moving components experience only rotation, current gas turbines offer improved durability and service life over reciprocating engines under equivalent usage.

The characteristics which allow the gas turbine to exhibit improved durability over the piston engine are, unfortunately, completely unlike anything a modern automobile mechanic has ever seen. Complete retraining of the nation's service personnel would be required in order to service a fleet of gas turbine powered automobiles. Likewise, the diagnostic technique and tools needed to determine faulty or failed gas turbine components would be somewhat different that those used on today's automotive engines.

We estimate that the cost of gas turbine diagnostic equipment will be no greater than the cost of the multi-function diagnostic devices now being used by up to date service facilities to diagnose conventional engines. Indeed, service establishments equipped to diagnose current fuel injection systems would probably have a good portion of the equipment needed to service the fuel control system of the gas turbine.

As with the Stirling engine, the potentially most troublesome component in terms of mechanic training is the combustor. Diagnosis of the fuel control and ignition system of the gas turbine's combustor will require that service personnel learn not just new ways of servicing a known system, but they must also understand a completely new combustion concept.

Unlike the Stirling, however, there are no new high technology components requiring additional or alternate service facilities. In fact, the gas turbine engine is mechanically simpler than today's reciprocating engines. If any change in service facilities is required, we anticipate that a reduction in the variety of different service tools and maintenance devices would be possible with a fleet of vehicles powered solely by gas turbine engines. The service establishments would still have to repair or replace engine bearings, bearing seals, spark plugs and the ignition system components, as well as a fuel control system. However, there will no longer be any valves, camshafts, valve lifters, rocker arms pushrods, pistons, rings, and water pumps.

The same reduction in components also results in improved service life. For example, as shown in the companion to this report, DOT-TSC-NHTSA-78-25, conventional automotive engines require replacement of water pumps once every 100,000 miles, cooling system maintenance every 24,000 miles, oil and filter changes approximately every 6000 miles, etc. Because the gas turbine has no cooling system per se, maintenance of this system is eliminated. Service to the reciprocating engine components is also eliminated. Because the gas turbine has a completely sealed lubrication system, contamination of the lubricant with combustion products is eliminated, and the oil change interval may be extended.

Current experience with experimental gas turbine powered buses indicate that the current state-of-the-art gas turbine vehicles run for 5000 to 6000 hours before any service is required.[1] At these intervals, replacement of the regenerator seals is required, as is an oil and filter change. At 45 miles per hour, this is equivalent to an oil change approximately every 250,000 miles .

To be competitive with today's conventional engines in terms of fuel economy, the gas turbines must run with turbine inlet temperatures which only the more exotic modern turbine materials can withstand. The replacement costs for these components, therefore, can be estimated as being very much higher than the replacement costs of the internal parts of a conventional engine. However, most current passenger car engines are capable of lasting as long as the rest of the vehicle without replacement. As we have seen, the life of the internal gas turbine components should exceed the normal 100,000 mile vehicle life by a factor of at least 2.5. Therefore, it is improper to consider replacement costs of the internal gas turbine components just as this study has not considered replacement of the internal components of conventional engines.

In conclusion, we have seen that the major impact of the gas turbines will be upon mechanics training and service intervals. A complete re-training of service personnel will be required in order to properly maintain a fleet of gas turbine powered vehicles. The number of routine scheduled maintenance intervals of the gas turbine engine will be greatly reduced from today's engines.

Secondary impacts of the gas turbine on vehicle service will be the new diagnostic equipment and the elimination of the cooling system and its associated pumps, hoses, and radiator as well as the elimination of all the reciprocating components of the conventional piston engine.

Thus, we feel that it is reasonable to predict that the gas turbine engine will result in a reduction of both the frequency and cost of maintenance. Scheduled maintenance intervals will be much longer than with conventional engines, and the number of components subject to unscheduled maintenance will be reduced. Since the only change in the service facilities will be the mechanic tranining, and diagnostic tooling, the required maintenance will cost no more than with conventional engines. The net results will be a reduction in maintenance costs over the life of the vehicle.

Engines will be designed and built in module form for ease of removal and replacement such as planned for the Ford gas turbine engine. These modules would be exchanged for factory rebuilt units.

REFERENCES FOR SECTION 4.12

1. Personal conversation, Mr. Richard F. Merrion, Manager Sales Engineering Detroit Diesel Allison, and Mr. Philip Gott, Arthur D. Little, March 2, 197

4.13 LOCKUP TORQUE CONVERTERS AND 4-SPEED AUTOMATIC TRANSMISSIONS

Lockup torque converters and automatic transmissions with four or more forward speeds are not new. In fact, the very first modern automatic transmission, the 1937 Oldsmobile "Safety" Transmission (so called because the driver did not have to use on hand for shifting), was a four-speed automatic unit with no torque converter at all. This unit shifted without disengaging the engine from the transmission in the same way that shifts with a locked up torque converter can be made. This transmission was marginally successful due to limitations of lubricants of the day, and not due to any deficiency inherent in the design.

In the early fifties, both Packard and Studebaker had three-speed automatic transmissions which incorporated a torque converter lockup in top gear. These transmissions were eventually discontinued because the lockup torque converter gave a more jerky shift than the competitive Ford and General Motors transmissions. The marketplace was demanding ultra smooth transmission performance.

Lockup, multi-speed automatic transmissions are still being made today, however, and are enjoying service life which makes them competitive in the marketplace. Virtually every transit (city) bus is equipped with the Allison "V" drive transmission. This unit is essentially just a torque converter with a lockup feature. The relatively harsh shift one feels in these buses is the engagement of the lockup clutch.

Another modern automatic transmission with more than three speeds and a lockup clutch is the Allison 6-speed automatic transmission known variously as the Powermatic, Reomatic, Torquematic, and the Transmatic. This transmission locks up the coverter when the torque multiplication of the torque converter is not needed. The converter unlocks for all shifts.

The marketplace is such that if these modern lockup transmissions had a poor service record and high maintenance costs, they would not long survive. These units have been produced for years and are quite successful. The Allison "V" drive lockup unit enjoys 100% market penetration in the urban bus field.

Recent experience by Arthur D. Little with lockup torque converters under contract DOT/TSC-1046 for the Department of Transportation, Transportation Systems Center, indicates that the use of a lockup torque converter can substantially reduce the oil temperature in a passenger car automatic transmission. This is a beneficial side effect which can potentially increase the oil change interval for automatic transmissions and may reduce heat caused feailure of clutch and band friction facings and also of oil seals.

Thus, historical experience of this type of automatic transmission leads us to believe that there will be no adverse change in the maintenance costs of these transmissions when installed in passenger cars. In fact, there may be an increase in component life and a reduction in the frequency of scheduled maintenance for these units.

4.13 CONCLUSIONS

Table 1-1 presents a summary of the impacts of future technology on automobile maintenance. As shown in the Table, the majority of the technological innovations will reduce or will not affect maintenance costs. With the exception of five innovations, the greatest impact on the service industry will be in retraining of mechanics, with seven of the fourteen innovations having little or no impact on the industry.

Those innovations which are expected to increase maintenance costs do so largely because of the requirement to replace expensive parts, and not due to the increased maintenance requirements. For example, the use of electronically controlled carburetion or fuel injection has the potential of decreasing the number of times a fuel system tune-up is required. The increased costs result from replacement of more expensive, major components. Replacement frequencies should not, however, increase as a result of these innovations.

The stratified charge engine is also listed as increasing maintenance costs. This is primarily due to the use of fuel injection equipment or the increase in the number of engine valves. These systems are expected to require replacement (fuel injection) or adjustment (multiple valve) at the same frequency as carburetors or valves, respectively, on conventional engines. The increase in costs is due to the replacement of more expensive equipment or an increase in the labor time involved in normal adjustments.

The introduction of electronic controls. fuel injection, diesels, and gas turbines are expected to require new diagnostic tools as well as significant retraining of mechanics. The last decade has shown tremendous growth in diagnostic instrumentation even for conventional engines, and, in general, the use of diagnostic tools has been accepted by the repair and service industry as well as the consumer. Furthermore, when these diagnostic tools have been used as part of a routine tune-up or other repairs, we have found that their use has not resulted in an increase in the repair fee. The equipment is generally amortized through an increase in productivity rather than through increased charges. Therefore, the new diagnostic equipment is not expected to increase repair costs.

It is also interesting to note that both the diesel and gas turbine engines use a fuel injection type of fuel control and distribution system. Therefore, it is most probably that a shop which has invested in a set of diagnostic equipment for fuel injection equipment will already be at least partially equipped to handle any engine with this type of fuel control. A completely separate set of diagnostic tools for alternate engines will not be required.

The only new technology which will cause a great, and presumably very expensive change in the repair and service industry is the Stirling engine. With their completely sealed, high pressure working fluid, these engines are completely different than any other type of engine the repair and service industry has ever handled. New storage and distribution systems will be required for the working fluid. High pressure charging facilities and accompanying safety equipment will also be required.

Since the percentage of the fleet which is equipped with Stirling engines will undoubtedly be quite small for the first five or so years after its introduction, the cost for these new facilities would be quite high relative to the number of cars that are available to use. If the costs for these facilities were to be amortized over only the fleet of Stirling powered vehicles, there would be a dramatic increase in maintenance costs. However, we feel that the successful introduction of any new technology such as the Stirling depends upon competitive maintenance costs. Therefore, we conclude that even though the required new facilities would be expensive, their cost would not be totally amortized by the Stirling fleet, but would either be spread out over the entire vehicle fleet, or reflected in the initial cost of the car.

5. METHODOLOGY FOR THE ASSESSMENT OF VEHICLE COMPONENT DURABILITY

5.1 INTRODUCTION

The assessment of component durability is extremely difficult to perform without entering a test mode. The automotive environment is one of the most difficult situations for which the vehicle engineer must design. In specifying product performance, it is not unusual to require a temperature range of 100° centigrade, forces in excess of 50's and 95% relative humidity[1]. Assessment of the durability of a component or a new technological innovation in a relatively quick, non-test way, requires an assessment methodology which assumes that the designers have or will have designed and developed components under laboratory and limited field tests simulating as much as possible the true automotive environment. The durability assessment methodology presented in this section is based upon that assumption. This methodology essentially examines those factors reasonably beyond the control of the component designer.

REFERENCES FOR SECTION 5.1

1. "Electronic Dashboard Displays," Automotive Engineering, May 1977

5.2 DURABILITY ASSUMPTIONS

In today's world of consumerism, it is inconceivable that a manufacturer will knowingly produce and sell a product or component which is less durable than his other products or those of his competition. To do so would invite disaster in the form of poor publicity, anti-manufacturer consumerist action, class action lawsuits and perhaps even "corrective" legislation. The latter two items do not occur often, but achieve wide publicity when they do, as with the case of "premature" body corrosion of some U.S. automobiles in Canada resulting in court action and legislated requirements for corrosion warranties. Since it is in the best interests of the manufacturers to avoid such occurrences, the first assumption is:

1) Component and vehicle manufacturers will make every reasonable effort to design new technologies for durability comparable to their own products and those of their competition.

The second assumption is one of longevity. Just what can be considered comparable durability? The assumption taken from Ford Motor Company, is:

2) 100,000 miles in the design life of non-safety related components[1]. Design life of safety components is much longer.

These two assumptions lead to a logical conclusion, which is the third assumption:

3) Factors which affect vehicle durability and cause premature component failure are those factors which are beyond the reasonable control of the vehicle or component designer.

REFERENCES FOR SECTION 5.2

1. Forgione, J., Verification Testing of the 1970 Anti-Theft Steering Column, SAE Paper 700582.

5.3 ASSESSIBLE FACTORS AFFECTING VEHICLE COMPONENT DURABILITY

Vehicle components are normally designed for a typical automotive environment and/or service condition. The "typical" environment, as defined at the time the component is designed, can change as the vehicles themselves change. For instance, the styling of a car usually dictates the diameter of the vehicle wheels. If an axle or a bearing is designed for suitable durability at a given load and a given vehicle speed with a 15-inch wheel, the durability may be compromised if the diameter of the wheel is changed to 13 inches because the rotational speed will increase.

Wheel diameter also influences the room available for brakes. The brake drums or discs and the appropriate activating mechanisms are located within the inner diameter of the wheel rim. As the wheel diameter decreases, so does the space available for brakes. The ability of brakes to dissipate heat is a function of the surface areas of the brake disc or drum. The smaller brakes required to fit inside smaller wheels are apt to experience higher temperatures than those which can fit inside larger wheels due to reduced surface area. Therefore, if two cars have the same weight but different size wheels, the brakes are apt to require more frequent maintenance in the car with smaller wheels.

In a similar manner, the under-hood temperature extremes, or the dwell time at these temperatures, may change as the size and/or style of the engine compartment changes. For instance, Ford Motor Company strongly recommends that the engine in their V-8 equipped Mustang II not be idled in traffic for more than 5 minutes[1]. This is to avoid buildup of excessive temperatures which could damage some power train components. This caution does not accompany that engine when it is installed in cars with larger engine bays. The vehicle factors which affect the temperature of various components can be assessed as an indication of durability.

If a component designed for a given load is subjected to a greater load, the life of that component may be reduced. If a technological innovation serves to increase the loading on a component designed for lesser loading, that component may indeed exhibit reduced durability. If, for example, a four cylinder engine which exhibits acceptable durability in a subcompact car is placed in an intermediate vehicle, the torque and power output required of this engine is suddenly increased for equivalent vehicle performance. If the engine were designed originally for only the loading of the subcompact car, it is very likely that the durability of that engine in the intermediate vehicle will be reduced from the level achieved in the smaller car.

The factors which are important and assessible in an evaluation of vehicle durability are, therefore:

- heat
- rotational speed
- engine and drivetrain loading
- brake loading

REFERENCES FOR SECTION 5.3

1. Ford Mustang II Owners Manual, 1975, Ford Motor Company

5.3.1 Heat

A critical factor for any mechanical or electrical device is the temperature at which it must operate. Currently, commercial quality electrical components are capable of withstanding temperatures up to 85° centigrade (185°F) without failure[1]. At present state-of-the-art, temperatures in excess of 85° centigrade can be expected to degrade component durability.

Mechanical devices are a bit more complicated, as extreme environmental temperatures affect them indirectly through lubricant degradation. The expected durability of an engine or transmission can be assessed by an examination of the temperatures and viscosities of its lubricant. Since it is the intent of this section to avoid testing, rough rules of thumb must be developed in order to conduct a first cut assessment of the impact of a technological innovation on the temperatures achieved by that innovation and/or the engine and transmission.

In an engine, acceptable durability appears to be attained if the viscosity of the oil as it flows through the bearing (the "apparent" viscosity) is above 6 centistokes (cSt) at 132°C (270°F)[2] in a high speed European engine. Other research has shown that bearing failure occurred with oils having an apparent viscosity of 3.2 cSt or less at 160°C (320°F) in an in-service fleet of U.S. police vehicles, while no failure occurred with an apparent viscosity of 3.8 cSt under the same conditions[3]. The apparent viscosity is used here because modern multi-grade oils tend to experience a temporary viscosity reduction under shear.

Data presented by Lane *et al* indicates that the viscosity loss is in the range of 20 to 43%[2] for different commercial multi-grade oils. The safe, no shear viscosities which would provide adequate lubrication under the above conditions are 7.8 cSt at 132°C (270°F) and 4.9 cSt at 160°C (320°F), if a 30% allowance is made for overall viscosity reduction with a well formulated oil.

The temperature of the oil also rises as the oil is sheared while passing between moving parts. In the range of apparent viscosities discussed above, oil temperature increased by between 30° and 45°C (54° and 81°F)[4]. The lower the apparent viscosity, the less the temperature rise. Hence, the oil pan temperatures corresponding to the operating temperatures in the previous paragraph are approximately 102°C (224°F) and 115°C (239°F) to achieve the required bearing temperature and viscosities.

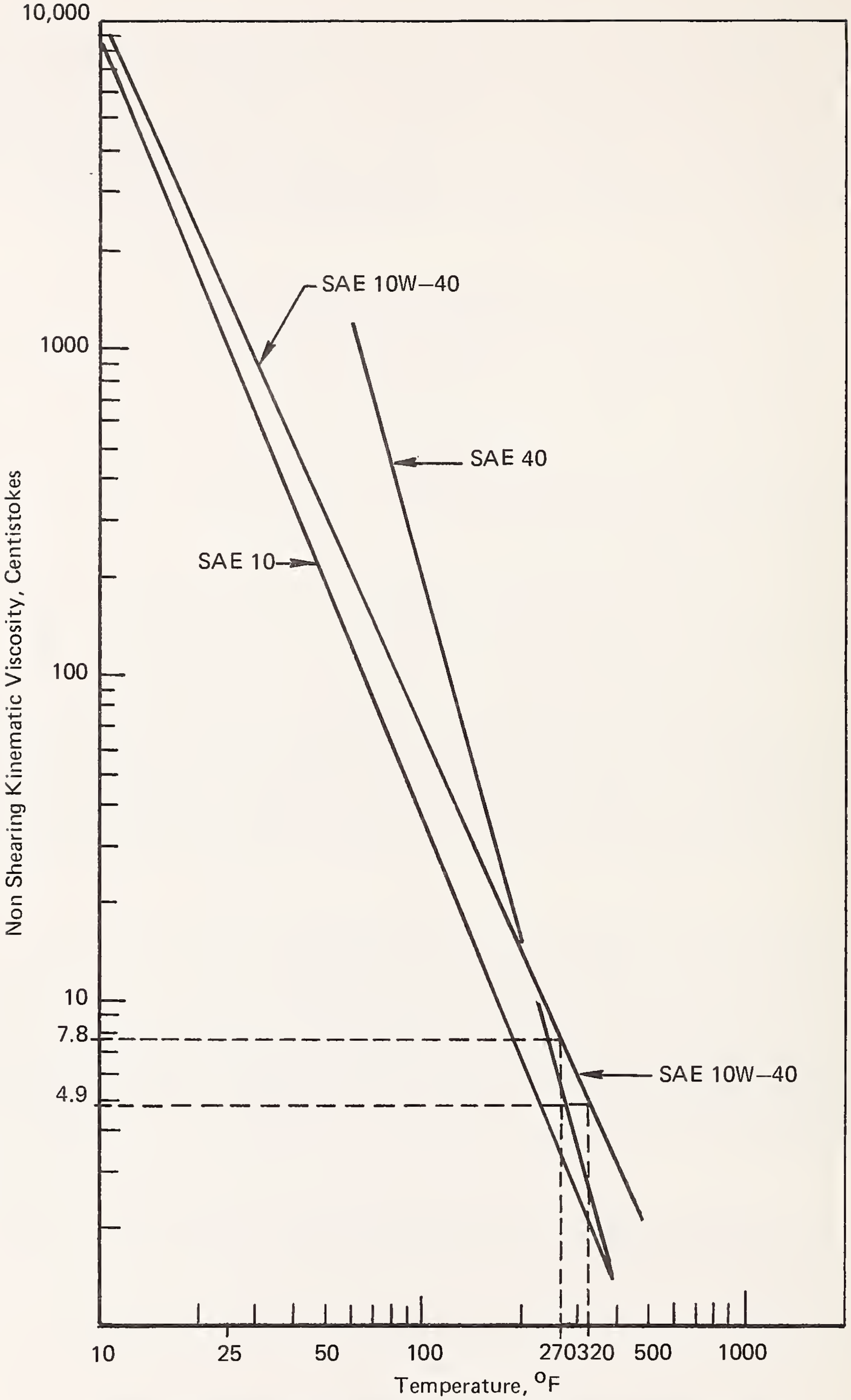
The viscosity of oil changes with temperature in a manner approximating Figure 5-1. It is apparent that 10W-40 multigrade oils provide only marginal engine protection at the temperature specified. In the evaluation of the durability of an engine, then, an examination of the oil temperatures actually achieved will allow an investigation to determine whether or not the engine is receiving proper lubrication. If the oil temperatures in the bearings result in oil viscosities lower than 7.8 cSt for high speed European type designs or 4.9 cSt for U.S. designs, the engine or component may have questionable durability.

Another indication of durability as a function of temperature is the life expectancy of automatic transmission fluid. Table 5-1, developed by the Automotive Service Council indicates a great reduction in the service life of the oil as the temperature increases.

Any assessment of component durability, then, should include an assessment of the temperatures which are achieved under normal and adverse operating conditions. The effect of these operating temperatures on the viscosity or life expectancey of the oil can then be reevaluated to determine if the life or maintenance requirements of the component will be adversely affected.

REFERENCES FOR SECTION 5.3.1

1. "Electronic Dashboard Displays," Automotive Engineering, May 1977.
2. Lane, Roberts, Tims, Measurement of the Viscosity of Multigrade Oils in a Running Engine, SAE Paper 770379, published in The Relationship Between Engine Oil Viscosity and Engine Performance, SAE publication SP 416
3. Stambaugh and Kopko "Behavior of Non-Newtonion Lubricants in High Shear Rate Applications", SAE Transactions, Vol. 82 (1973 paper 730487)



Source: Developed From Marks' Handbook for Mechanical Engineers McGraw-Hill Book Company, 1967.

FIGURE 5-1. SAE OIL VISCOSITY VERSUS TEMPERATURE

TABLE 5-1 DURABILITY VS. TEMPERATURE OF AUTOMOTIVE TRANSMISSION PARTS

TEMPERATURE	LIFE EXPECTANCY
175°F	100,000 miles
195°F	50,000 miles
212°F	25,000 miles
235°F	12,500 miles
255°F	6,250 miles
275°F	3,000 miles
295°F	1,500 miles
315°F	750 miles
335°F	325 miles
375°F	160 miles
395°F	40 miles
410°F	30 minutes

Temperatures above 390°F cause transmission metals to twist and warp.

Source: Automotive Service Council

5.3.2 Rotational Speed

The angular velocity of a rotating shaft affects two things:

1) Heat generated within a bearing
2) Number of load/unload cycles experienced per unit time

Heat is generated within a bearing primarily due to the shearing of the lubricant. As the shaft speed increases, so does the unit thermal energy per unit time, and the temperature rises. As the temperature rises, the viscosity of the lubricant decreases. If either the critical minimum viscosity is reached or the lubricant degrades through oxidation, metal to metal contact, galling, and bearing failure will occur.

The temperature rise (°F) in a spherical roller type bearing can be estimated from the equation:

$$\Delta T = \frac{DN}{2000} \quad (1)$$

where ΔT = Temperature rise above ambient °F

D = Shaft diameter, millimeters

N = RPM

If the total temperature of the bearing is such that the viscosity of the lubricant drops below approximately 6 cSt, a reduction in durability can be expected.

If the component shaft speed is increased, but the lubricant is still adequate for the prevailing condition, durability of the shaft roller or ball bearings will still be decreased. This change in durability will be due to the increase in the number of load/unload cycles experienced by the bearing per unit time.

Properly designed, sized, and installed roller or ball bearings normally fail due to fatigue. Because the rollers or balls contact the bearing race in either finite lines or single points (at least thoretically) very high contact stresses are developed in both the rollers or balls and their respective races. As the bearing is rotated, the bearing materials undergo a very high number of stress cycles as the rollers or balls rotate. For every revolution of the shaft, the roller or balls may rotate four, six or even more than ten times. Also, for each bearing revolution, the races are loaded or unloaded each time the many balls or roller pass over it and there may be eight or more rolling elements in each bearing. Thus, the high contact stresses and the relatively high number of stress cycles which can be accumulated in a short time result in a finite fatigue life of the bearing materials. As the surfaces of the bearings' rolling elements and races become fatigued, the materials crack, spall and pit, reducing the contact surface area even further and leading to rapid bearing failure.

It can be seen, then, that a change in the rotational speed of a shaft directly influences bearing life due to a change in the number of stress cycles which the bearing experiences in a given time frame.

REFERENCES FOR SECTION 5.3.2

1. Hafner, E.R., "Proper Lubricating the Key to Better Bearing Life, Part 2", Mechanical Engineering, November 1977

5.3.3 Engine and Drivetrain Loading

Any technological innovation which alters engine and/or drivetrain loading may affect durability. Durability can be degraded by a change in loading or operating conditions which cause:

- improper lubrication
- excessive temperatures
- higher unit stress

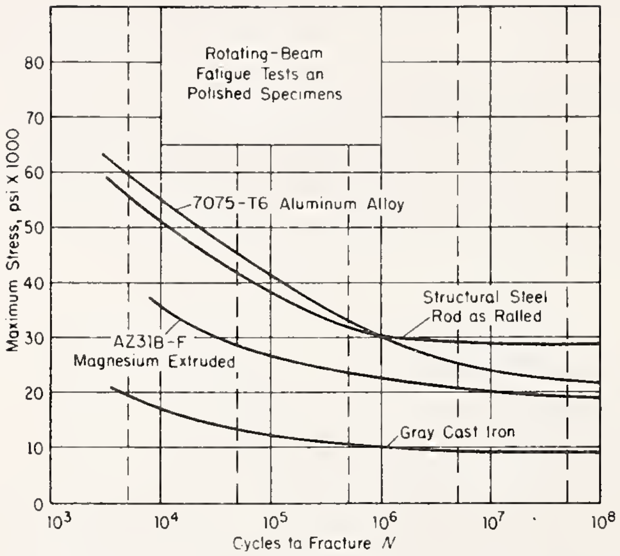
Engine cylinder wall loading might be added to this list. However, if proper lubrication is maintained, and the temperatures achieved are not extreme for the piston and cylinder materials, piston and cylinder "running wear is very little influenced by load or piston speed"[7]. Previous sections have covered heat buildup and lubrication requirements.

Higher unit stresses, particularly with anti-friction (roller or ball) bearings, can have a direct impact on the fatigue life of a component. As discussed in the previous section, the number of stress cycles which a material can undergo is limited under high unit stress conditions. Figure 5-2 illustrates the typical relationship of the unit stress versus the number of stress cycles before fatigue failure occurs. Under low unit stress conditions, the fatigue life is almost infinite as the characteristic failure curve becomes insensitive to the stress. (Note that such low unit stresses are impossible to reach with anti-friction bearings due to the almost infinitely small contact area.) As the unit stress level is increased, the fatigue life of the part becomes finite and, indeed, quite limited.

To put Figure 5-2 in proper perspective, the wheels on a car undergo approximately 10^3 cycle every minute at highway speeds. In 100,000 miles, they undergo 10^8 cycles, as do the axle shafts. The drivetrain and engine undergo approximately three times as many cycles as the wheels.

With the materials listed in Figure 5-2, it is clear that the unit stresses must be relatively low if the vehicle components are to last 100,000 miles. Any significant increase in unit stress will markedly decrease the fatigue life of the rotating components.

An assessment of the durability of a new component or operating conditions, then, should include an evaluation of the change in unit stress levels normally experienced by a component with acceptable durability.



Source: Mabie, H., *Mechanisms and Dynamics of Machinery* – John Wiley & Sons, New York 1966.

FIGURE 5-2. TYPICAL FATIGUE LIFE VS. UNIT STRESS RELATIONSHIPS

REFERENCES FOR SECTION 5.3.3.

1. Smith, P.H., The Design and Tuning of Competition Engines Revised Fifth Edition, Robert Bentley, Inc. 1971.

5.3.4 Brake Loading

The life expectancy of brake pads is mainly a function of:

- the frequency of brake usage
- the temperatures of the brake components

The first parameter is beyond the control of the vehicle designer and is a function of driver habits and vehicle usage. The temperature of the brake components is a function of the swept areas of the brakes and the availability of a cooling air flow around the brakes.

The greater the swept area of the brakes, the greater the surface area and total mass of material over and into which the generated heat may be dissipated. As the brake components change in size so that the swept area is changed, so will the heat dissipation capability of the brakes.

High temperatures tend to vaporize the resins which bond the brake pad aggregate materials together. As these resins are vaporized, the ability of the aggregates to stick to one another is lost and and the brake pad literally disintegrates into a fine dust. This normally occurs only at the surface of the brake lining material where it contacts the moving surface of the brakes as most of the heat is transferred from the pad through this rotating member. The heat absorbtion and dissipation capabilities of the brakes are therefore a function of the area of the rotating brake components which contact the brake drums or discs (the so-called swept area). The larger the swept area, the greater the heat dissipation capability of the brakes and the longer they will last, or the greater their load carrying ability for equal durability.

5.4 CONCLUSIONS

An assessment of the durability of a vehicle component or a technological innovation, such as reduced vehicle size or weight, or both, must take into account those factors which can affect durability. Such factors include:

- Styling, as it influences
  - engine bay size (under-hood temperatures)
  - wheel diameter (rotational speed)
  - aerodynamic drag

- Temperature Extremes
- Vehicle Weight, as it influences
    - engine loading
    - drivetrain loading
    - brake loading
- Wheel Diameter, as it influences
    - drivetrain rotational speed
    - swept area of brakes

Each of these must be examined in detail as they are affected by, or as they affect a vehicle or component change.

6. HIGH VOLUME AFTERMARKET ITEMS AND THEIR MODES OF FAILURE

The aftermarket items which represented the bulk of the automotive wholesalers unit volume in 1967 and 1975 are presented in Tables 6-1 and 6-2. The approximate market share of each item is also presented in these Tables. Change in the relative ranking of the items from 1967 to 1975 are as a result of an increase in the do-it-yourself market, new car dealers, and the specialty shops, none of whom patronize the wholesalers to any significant extent, also account for some discrepancies in the rank ordering of some components in these tables and in Chapter 6 of the companion to this report, DOT-TSC-NHTSA-78-25. Nonetheless, Tables 1 and 2 and the items in Chapter 6, are correlated well, and these tables are a reasonable representation of the aftermarket items.

6.1 FAILURE MODES

An examination of these components and their general modes of failure resulted in the development of the following list of failure modes:

- contamination and corrosion by dirt and water
- bearing wear and failure due to overload
- heat
- loss or degradation of lubricant or fluid
- age
- normal wear
- failure of gaskets and seals

These failure modes can affect one or more areas of a component, and of course, one failure mode can lead to another before actual failure occurs. For instance, a water pump may be considered to have failed as soon as its seal has worn allowing water to leak out. However, the failure of an oil seal in a differential case will not cause the differential to fail, but will allow the lubricant to leak out. Loss of lubricant will cause differential failure, while the reduction of the oil seal's effectiveness caused the loss of lubricant.

TABLE 6-1 HIGH VOLUME AFTERMARKET ITEMS, 1967
SOLD THROUGH AUTOMOTIVE WHOLESALERS

PERCENT OF TOTAL	ITEM
8.8	Exhaust System Components
7.6	*Ignition Points, Rotors, Condensers, Distributor Cars, Coils
7.3	*Spark Plugs
6.5	Batteries
6.5	*Filters
4.4	*Belts and Hoses
3.9	Brake Lining & Lined Shoes
3.4	Gaskets and Seals
3.3	Shock Absorbers
2.4	Engine Bearings
2.3	Roller and Ball Bearings
2.2	Piston Rings
2.1	Lamps and Flashers
2.1	Brake Parts & Fluid
2.1	Fuel Pumps & Parts
2.0	Carburetors & Parts (New)
2.0	Clutch Assemblies & Parts
1.5	Wipers 4 Blades
1.4	Wire & Cables
1.4	Ball Joints & Tie Rod Ends
1.3	Alternators & Generators (Rebuilt)
1.3	*Anti-Freeze
.9	Automatic Transmission Parts

*Replacement of these units part of unscheduled maintenance

SOURCE: Arthur D. Little Estimates Based Upon Economist Intelligence Unit and Automotive Services Industry Association Data.

TABLE 6-2 HIGH VOLUME AFTERMARKET ITEMS, 1975 SOLD THROUGH AUTOMOTIVE WHOLESALERS

Percent of Total	Item
19.3	Exhaust System Components
9.0	Filters*
7.8	Ignition Points, Rotors, Condensers, Distributor Caps, Coils*
7.8	Spark Plugs*
5.2	Belts and Hoses*
4.5	Shock Absorbers
4.4	Batteries
3.3	Ball Joints and Repair Kits
2.8	Bearings, Including Universal Joints Other than Engine Bearings
2.7	Gaskets and Seals
2.3	Water Pumps (New)
2.2	Wire and Cables
2.2	Brake Shoes and Pads (New)
2.0	Clutch Components (Rebuilt)
2.0	Alternators and Generators (Rebuilt)
1.9	Power Brake Units (Rebuilt)
1.8	Water Pumps (Rebuilt)
1.8	Lamps and Flashers
1.7	Brake Master Cylinders and Wheel Cylinders
1.7	Carburetors (New) and Repair Kits
1.6	Antifreeze*
1.5	New Alternators, Generators, and Starters
1.4	Fuel Pumps and Repair Kits
1.3	Starter Motors (Rebuilt)
1.2	Carburetors (Rebuilt)
1.2	Wiper Blades, Arms, and Motors
1.1	Piston Rings
1.1	Wheel Cylinders
1.0	Air Conditioners and Parts
1.0	Engine Bearings, Internal
.9	Brake Drums and Hubs
.2	Others

TABLE 6-2. HIGH VOLUME AFTERMARKET ITEMS, 1975 SOLD THROUGH AUTOMOTIVE WHOLESALERS (Continued)

PERCENT OF TOTAL	ITEM
.9	Thermostats
.9	Starter Motors, Rebuilt
.8	Brake Shoes & Parts (Rebuilt)
.4	Water Pumps (Rebuilt)
20.3	Others

SOURCE: Arthur D. Little Estimates Based Upon Economist Intelligence Unit and Automotive Service Industry Association Data

* Replacement of these units are a Part of Scheduled Maintenance.

Table 6-3 presents the primary failure modes of the high volume aftermarket items.

6.2 FAILURE ANALYSIS METHODOLOGY

There are three areas in which a component may fail:

- component material
- electrical items
- moving parts

Each of these areas must be examined in terms of the failure modes to determine the vulnerable areas of the component. Figute 6-1 presents the relationship between failure modes and component parts.

Materials may fail due to aging, corrosive attack by water, plugging by dirt, and/or distortion or loss of strength due to excessive temperature, or embrittlement due to extreme cold.

Electrical components can fail due to short circuiting by water and/or dirt, excessive heat or cold, and/or failure of a gasket or seal which allows contamination by dirt and water. The vulnerability of the electrical parts of a component must be examined in terms of its packaging and the environment in which it is placed. The capabilities of electric components are discussed in Section 5.3.1.

Moving parts must be supported by bearings of some sort, and the moving surfaces are usually protected from abrasive dirt by shaft or other types of seals, and are lubricated to minimize wear. Obviously, loss of lubricant or failure of these seals can lead to premature failure. As discussed in Section 5.3.3, bearing loads are critical determinants of bearing life, as are the rotational speeds. Excessive heat can lead to distortion and binding of moving parts.

Failure modes of moving parts are also interactive in that excessive heat can degrate a lubricant to a point where it is ineffective, while extreme cold can cause a lubricant to thicken so much that it cannot be

TABLE 6-3 PREDOMINANT FAILURE MODES OF HIGH VOLUME AFTERMARKET ITEMS

Age	Dirt and Water	Temperature Extremes	Failure of Gaskets & Seals
Ignition Parts	Exhaust System	Hoses	Shock Absorbers
Belts & Hoses	Filters	Batteries	Ball Joints
Batteries	Ball Joints	Bearings	Bearings
Gaskets and Seals	Brake Units	Gaskets & Seals	Water Pumps
Wire and Cable	Carburetors	Brake Shoes & Pads	Carburetors
Lamps & Flashers	Alternators	Alternators & Generators	Fuel Pumps
Antifreeze	Starter Motors	Starter Motors	
Fuel Pumps	Wheel Cylinders	Piston Rings	
Wiper Blades & Arm	Brake Drums & Hose		

Normal Wear	Loss or Degradation of Lubricant	Bearing Wear and Failure Due to Overload
Spark Plugs	Shock Absorbers	Ignition Points
Ignition Parts	Bearings	Bearings
Belts	Piston Rings	Water Pumps
Ball Joints		Alternators & Generators
Bearings		
Brake Shoes & Pads		
Clutch Components		
Alternators & Generators		
Brake Units		
Carburetors		
Fuel Pumps		
Starter Motors		
Wiper Motors		
Piston Rings		
Brake Drums & Hubs		

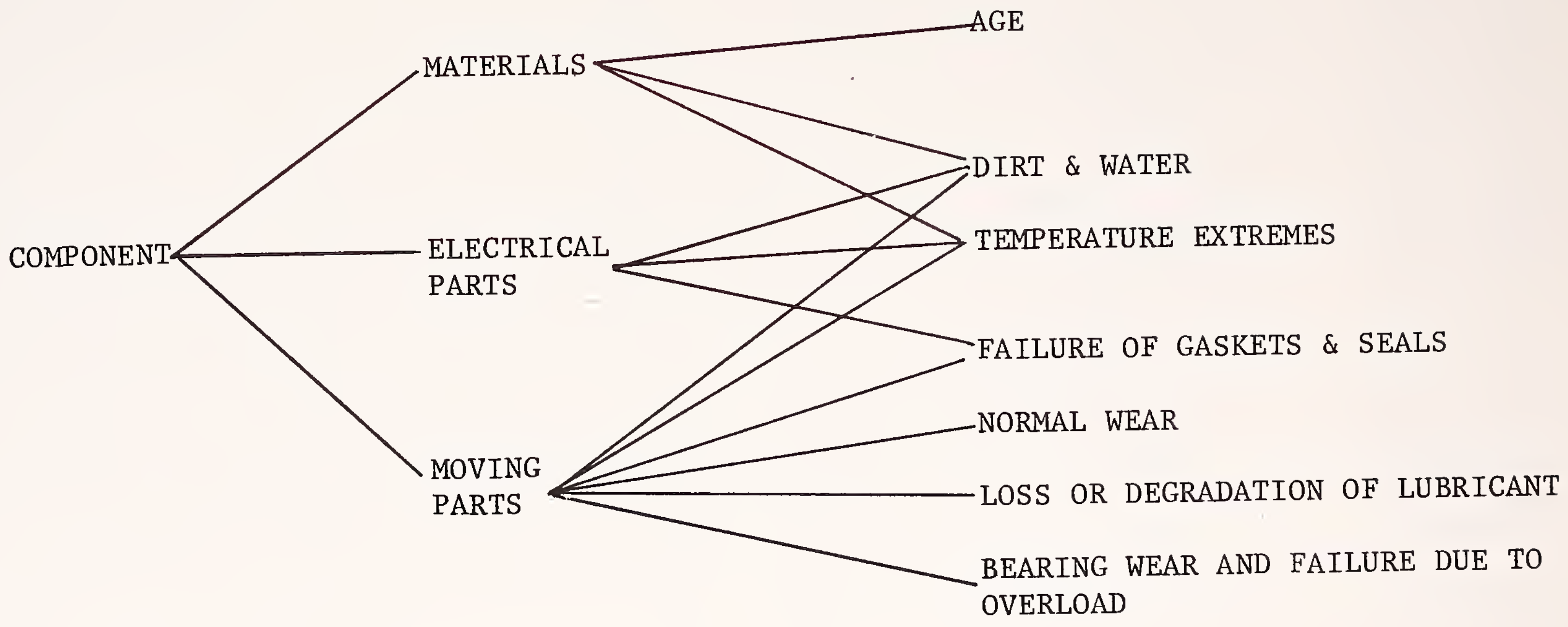


FIGURE 6-1. FAILURE MODE FAULT TREE

properly distributed. As mentioned previously, failure of a gasket or a seal can also lead to a loss of a lubricant or contamination by abrasive dirt or corrosive water.

The specific effects of heat, bearing loads, rotational speeds, and lubricant viscosities are discussed in Section 5 of this report.

6.3 SUMMARY

An examination of the failure modes of a given component can be accomplished by determining those areas of each component which are the most vulnerable to the condition of its use. If the threatening condition to which a component area is vulnerable is exacerbated, premature failure of that component can be expected.

APPENDIX A

COMPUTER GENERATED PARAMETRIC RELATIONSHIPS OF MAINTENANCE COSTS VERSUS ENGINE SIZE, VEHICLE WEIGHT, BODY CLASS, AND MODEL YEAR

See pages A-1, B-2 and B-3 for description of vehicles and list of vehicle identification numbers (VID).

Figures A-1 through A-102 are graphs of average maintenance costs for each year of use. The first group of figures (A-1 to A-8) are the average material costs, followed by the labor costs (Figures A-9 to A-14); the third grouping (Figures A-15 to A-24) is the sum of the material and labor costs. The vertical scale is cost in dollars per year, and the horizontal scale is the number of years of age. For all these plots, the labor rate and material costs used were those used at an auto dealers facility.

The same pattern (material, labor and total costs) is repeated for the body class for each manufacturer grouping; by weight class for all manufacturers; by weight class for each manufacturer; by engine displacement size for all and for each manufacturer.

The last 3 figures A-103 to A-105 are graphs of the scheduled, unscheduled and total life cycle (10 years or 100,000 mile) cost. The costs are plotted against the model year.

TABLE OF CONTENTS FOR APPENDIX A

FIGURE	CLASSIFICATION*	VID NOS. INCLUDED	PAGE FOR YEARS INCLUDED	COST**
A-1	LB	1,2,3 & 4	C-1	a
A-2	SB	5,6,7,8 & 9	C-2	a
A-3	IB	10,11,12,13 & 14	C-2	a
A-4	CB	15,16,17,18,19, 20,21 & 22	C-2	a
A-5	SCB, USA	23,24,25,26,27, 28 & 29	C-1	a
A-6	SCB, Foreign	30	C-1	a
A-7	SCB, Foreign	31,32,33,34	C-1	a
A-8	Trucks	35,36,37 & 38	C-1	a
A-9	LB	1,2,3 & 4	C-1	b
A-10	SB	5,6,7,8 & 9	C-2	b
A-11	IB	10,11,12,13,14	C-2	b
A-12	CB	15,16,17,18,19 20,21,22	C-2	b
A-13	SCB, USA	23,24,25,26,27 28,29	C-1	b
A-14	SCB, Foreign	30	C-1	b
A-15	SCB, Foreign	31,32,33,34	C-1	b
A-16	Trucks	35,36,37,38	C-1	b
A-17	LB	1,2,3,4	C-1	c
A-18	SB	5,6,7,8,9	C-2	c
A-19	IB	10,11,12,13,14	C-2	c
A-20	CB	15,16,17,18,19, 20,21,22	C-2	c
A-21	SCB, USA	23,24,25,26,27 28,29	C-1	c
A-22	SCB, Foreign	30	C-1	c
A-23	SCB, Foreign	31,32,33,34	C-1	c

TABLE OF CONTENTS FOR APPENDIX A (Continued)

TABLE OF CONTENTS FOR APPENDIX A (Continued)

TABLE OF CONTENTS FOR APPENDIX A (Continued)

FIGURE	CLASSIFICATION*	VID NOS. INCLUDED	PAGE FOR YEARS INCLUDED	COST**
A-67	WC 2601-3200	15,17,18,19,20,21 25,27,29	C-4	d
A-68	WC 1500-2600	23,24,26,27,28 30,31,32,34	C-5	d
A-69	WC > 4000	1,2,3,4,5,6,7,8 10,11,12,13	C-3	e
A-70	WC 3601-4000	6,8,9,10,11,12,13 14,15,16,17,22	C-3	e
A-71	WC 3201-3600	10,12,13,14,15,16 17,18,19,22	C-4	e
A-72	WC 2601-3200	15,17,18,19,20,21 25,27,29	C-4	e
A-73	WC 1500-2600	23,24,26,27,28 30,31,32,34	C-5	e
A-74	WC > 4000	1,2,3,4,5,6,7,8 10,11,12,13	C-3	f
A-75	WC 3601-4000	6,8,9,10,11,12,13 14,15,16,17,22	C-3	f
A-76	WC 3201-3600	10,12,13,14,15,16 17,18,19,22	C-4	f
A-77	WC 2601-3200	15,17,18,19,20,21 25,27,29	C-4	f
A-78	WC 1500-2600	23,24,26,27,28, 30,31,32,34	C-5	f
A-79	ED > 371	1,2,3,4,6,7,8,11	C-6	a
A-80	ED, 301-370	5,6,7,8,9,10,12 13,14,15,16,17,22	C-6	a
A-81	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	a
A-82	ED 50-150	23,24,26,27,28,30 31,32,34	C-7	a
A-83	ED > 371	1,2,3,4,6,7,8,11	C-6	b
A-84	ED 301-370	5,6,7,8,9,10,12 13,14,15,16,17,22	C-6	b
A-85	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	b

TABLE OF CONTENTS FOR APPENDIX A (Continued)

FIGURE	CLASSIFICATION*	VID NOS. INCLUDED	PAGE FOR YEARS INCLUDED	COST**
A-86	ED 50-150	23,24,26,27,28 30,31,32,34	C-7	b
A-87	ED > 371	1,2,3,4,6,7,8,11	C-6	c
A-88	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	c
A-89	ED 301-370	5,6,7,8,9,10,12 13,14,15,16,17,22	C-6	c
A-90	ED 50-150	23,24,26,27,28 30,31,32,34	C-7	c
A-91	ED > 371	1,2,3,4,6,7,8,11	C-6	d
A-92	ED 301-370	5,6,7,8,9,10,12,13 14,15,16,17,22	C-6	d
A-93	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	d
A-94	ED 50-150	23,24,26,27,28 30,31,32,24	C-7	d
A-95	ED > 371	1,2,3,4,6,7,8,11	C-6	e
A-96	ED 301-370	5,6,7,8,9,10,12,13 14,15,16,17,22	C-6	e
A-97	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	e
A-98	ED 50-150	23,24,26,27,28 30,31,32,34	C-7	e
A-99	ED > 371	1,2,3,4,6,7,8,11	C-6	f
A-100	ED 301-370	5,6,7,8,9,10,12,13 14,15,16,17,22	C-6	f
A-101	ED 151-300	15,17,18,19,20,21 27,29,25	C-7	f
A-102	ED 50-150	23,24,26,27,28 30,31,32,34	C-7	f
A-103	US Mfr.	5,6,7,8,11,12,13,14 16,17,21,29	All Years	g
A-104	US Mfr.	5,6,7,8,11,12,13,14 16,17,21,29	All Years	h
A-105	US Mfr.	5,6,7,8,11,12,13,14 16,17,21,29	All Years	i

TABLE OF CONTENTS FOR APPENDIX A (Continued)

* Codes for Classifications Column

LB is Luxury Body

SB is Standard Body

IB is Intermediate Body

CB is Compact Body

SCB is Subcompact Body

WC is Weight Class in Pounds

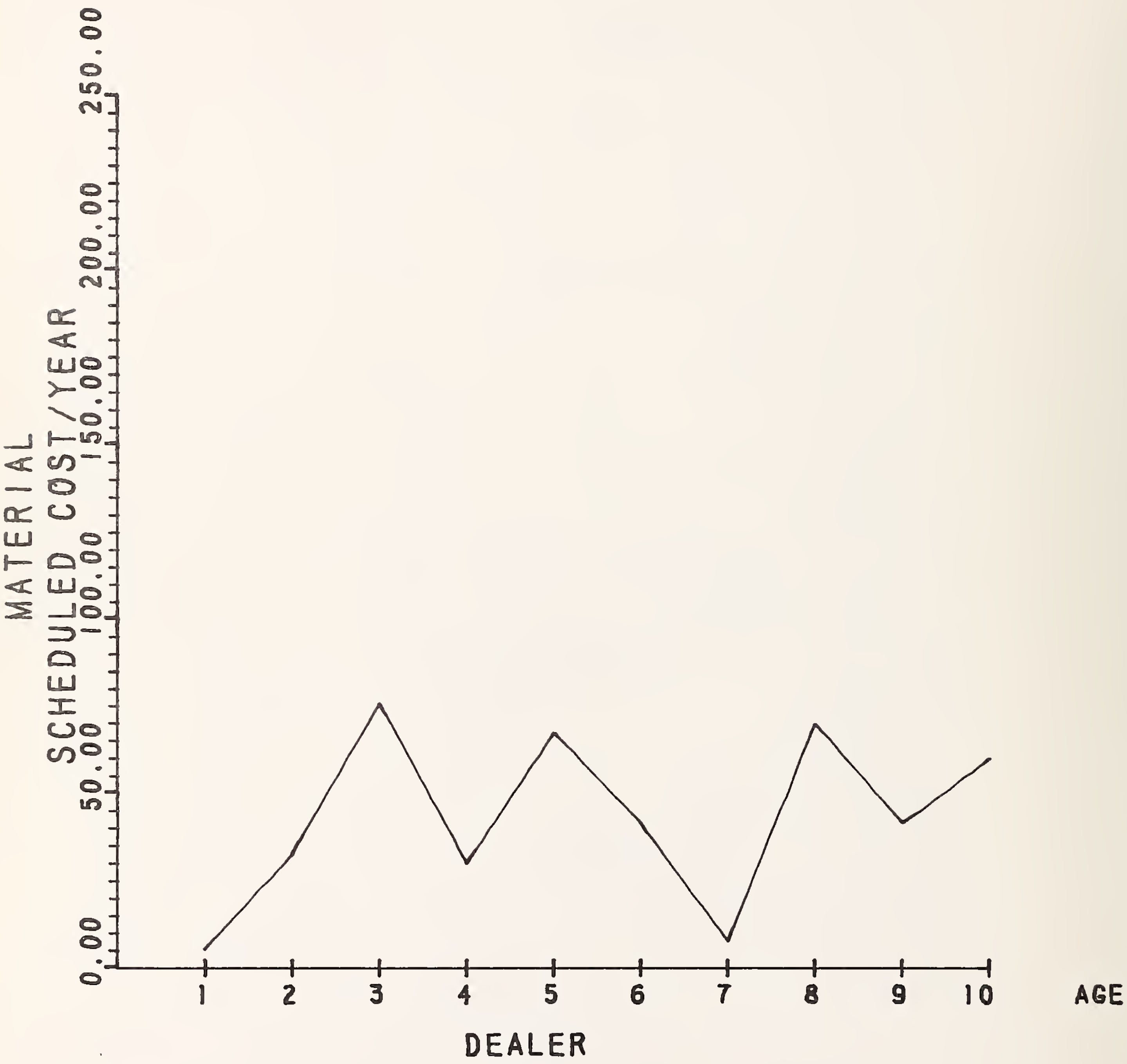
ED is Engine Displacement in CID

**Codes for Cost Column

a	Average Material Cost of All Manufacturer's
b	Average Labor Cost of All Manufacturer's
c	Average Total Cost of All Manufacturer's
d	Average Material Cost By Manufacturer
e	Average Labor Cost By Manufacturer
f	Average Total Cost By Manufacturer
g	Average Scheduled Costs By Year
h	Average Unscheduled Costs By Year
i	Average Total Costs By Year

VEHICLE IDENTIFICATION (VID) NUMBER

VID #	VEHICLE DESCRIPTION
1	Buick Electra 225
2	Cadillac Eldorado
3	Cadillac DeVille
4	Lincoln Continental
5	Chevrolet Impala/Belair
6	Ford Galaxie - Custom
7	Chrysler Newport
8	Plymouth Fury/Grand Fury
9	AMC Ambassador
10	Chevrolet Chevelle
11	Pontiac Grand Prix
12	Ford Torino
13	Plymouth Satellite/Belvedere
14	AMC Matador
15	Chevrolet Nova
16	Chevrolet Camaro
17	Ford Mustang
18	Ford Maverick
19	Dodge Dart
20	Plymouth Valiant
21	AMC Hornet
22	AMC Javelin
23	Chevrolet Vega/2300
24	Buick Opel Manta/1900 Coupe
25	Oldsmobile Starfire
26	Ford Pinto
27	Ford Capri 2600/1600/2000/2800
28	Dodge Colt
29	AMC Gremlin
30	VW Beetle/Rabbit
31	Toyota Corolla 1600
32	Datsun PL 610/510
33	Mazda RX 3 Coupe/R-100/RX 2
34	Honda Civic
35	Chevrolet C-10 Truck
36	Chevrolet C-20 Truck
37	Ford F-100
38	Ford F-250



VID BET I 4 YEAR LT 7 LUXURY BODY CLASS

FIGURE A-1

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS

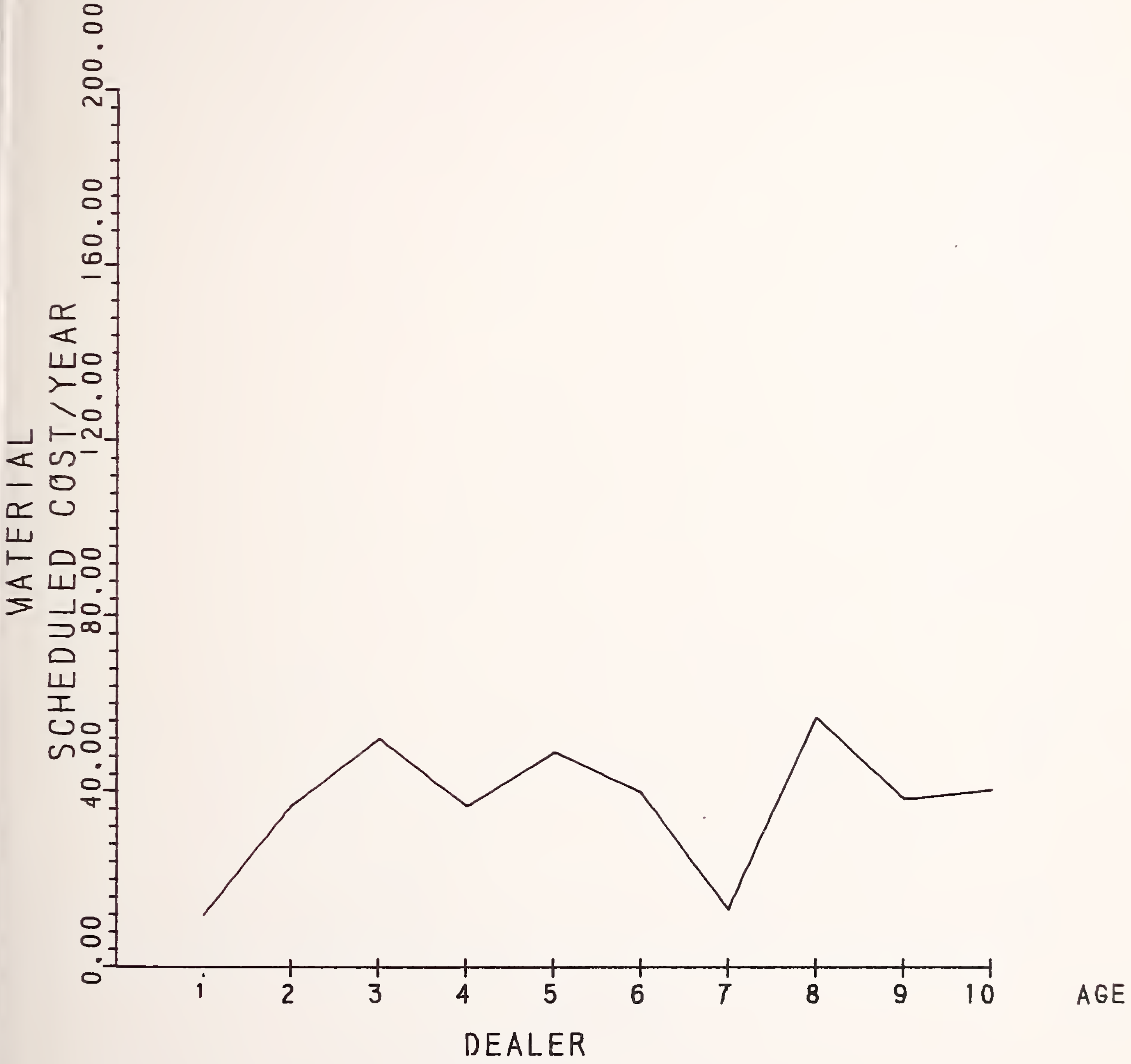


FIGURE A-2

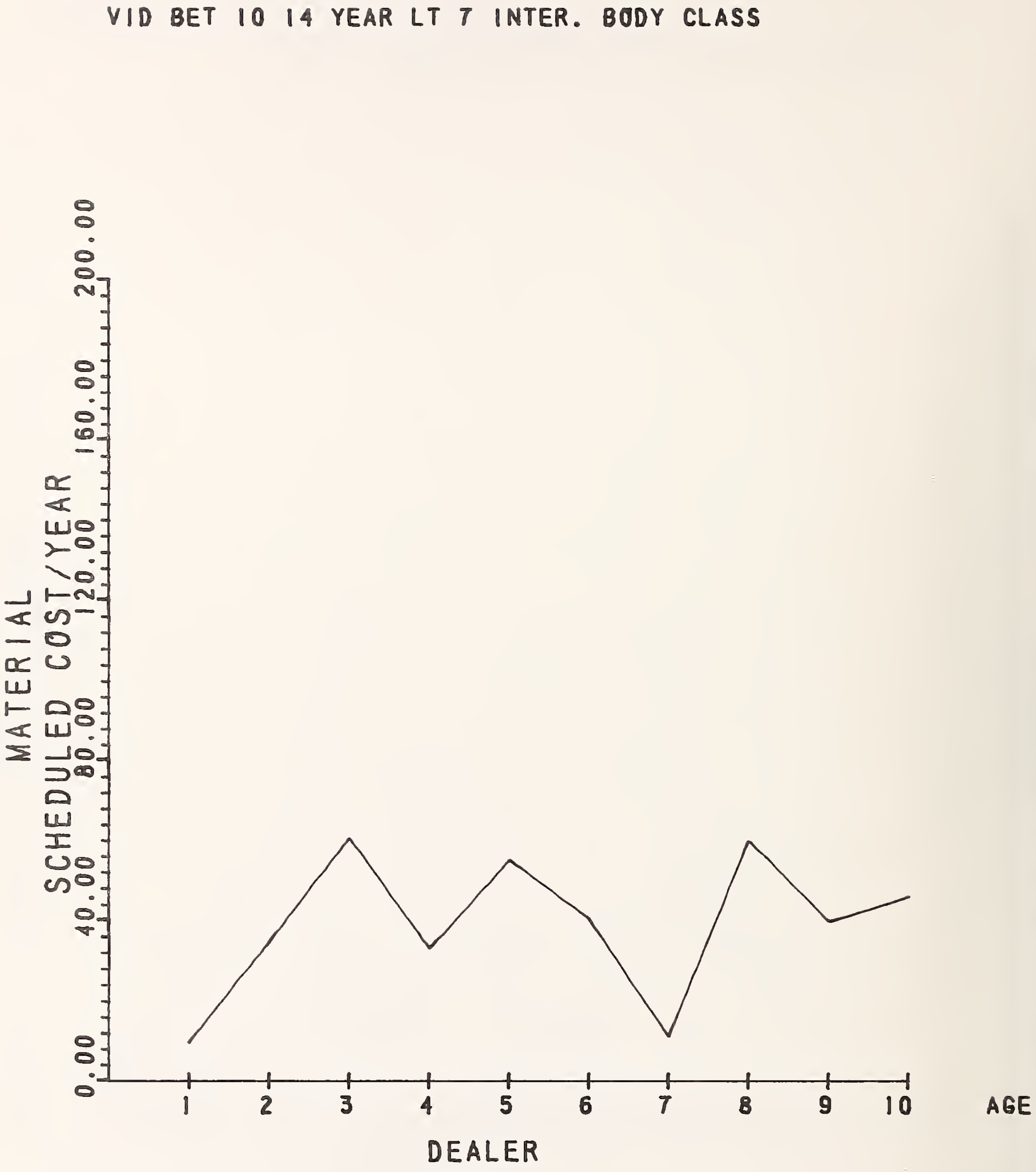
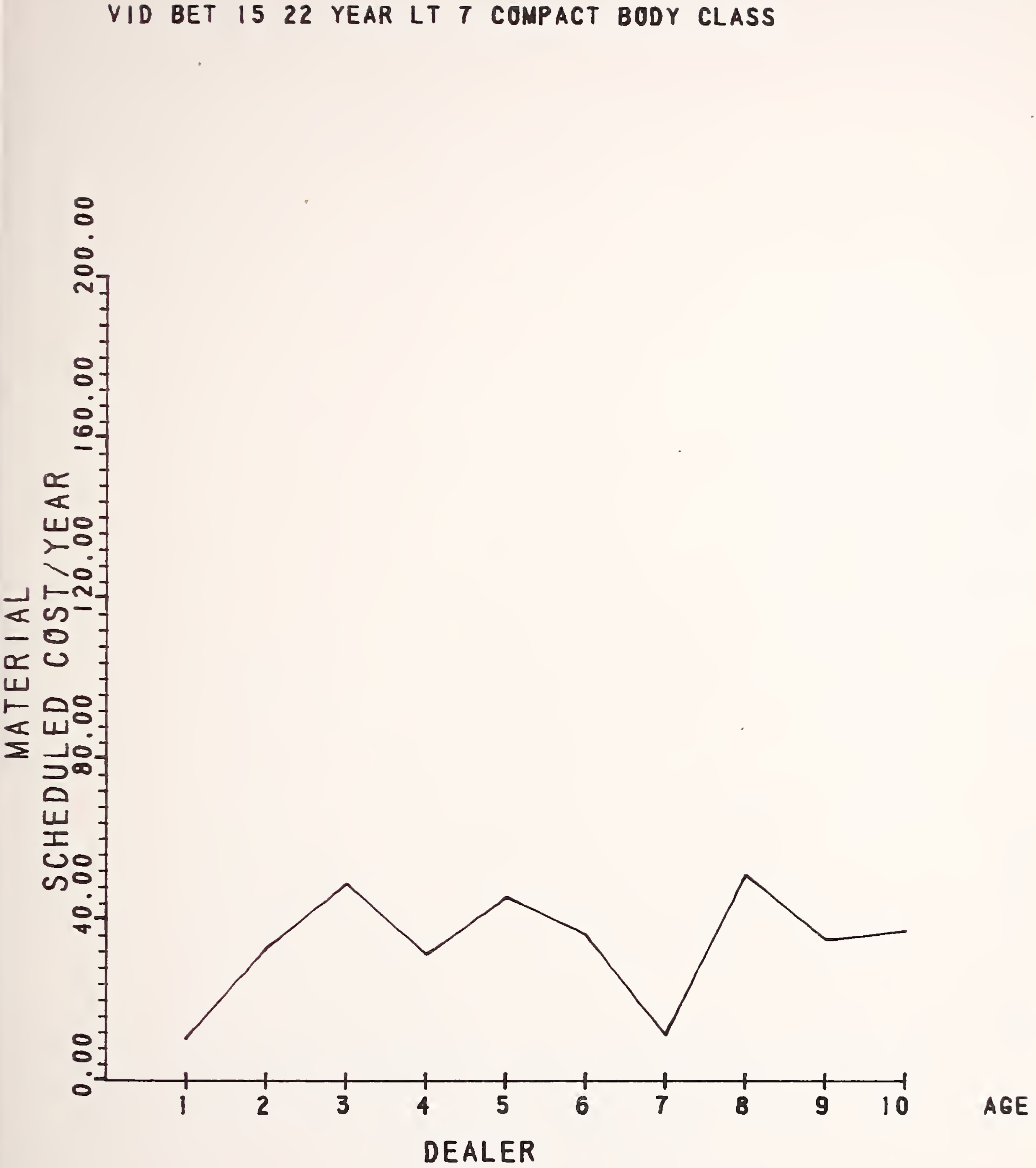

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-3



VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS

FIGURE A-4

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CLASS USA

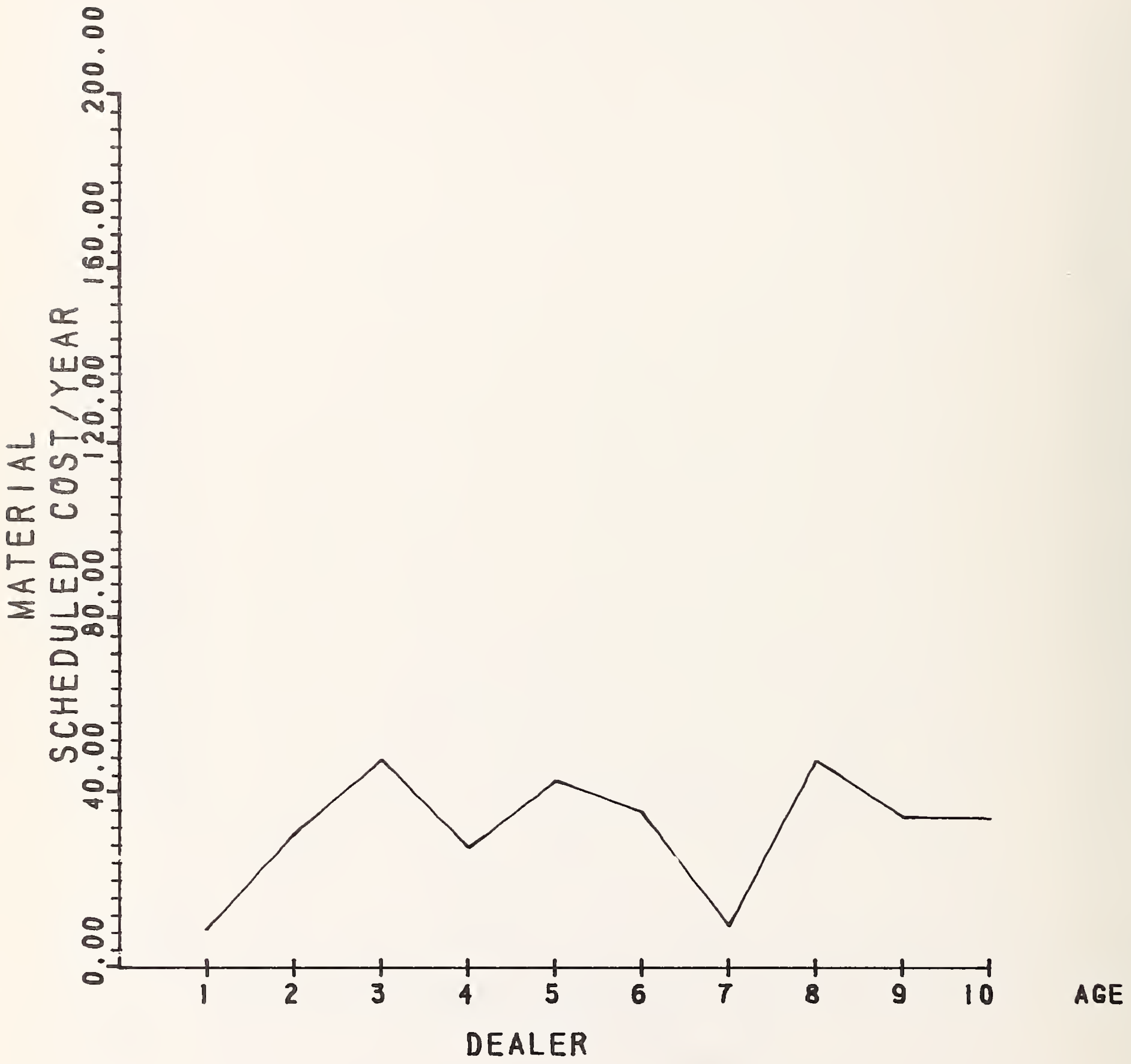


FIGURE A-5

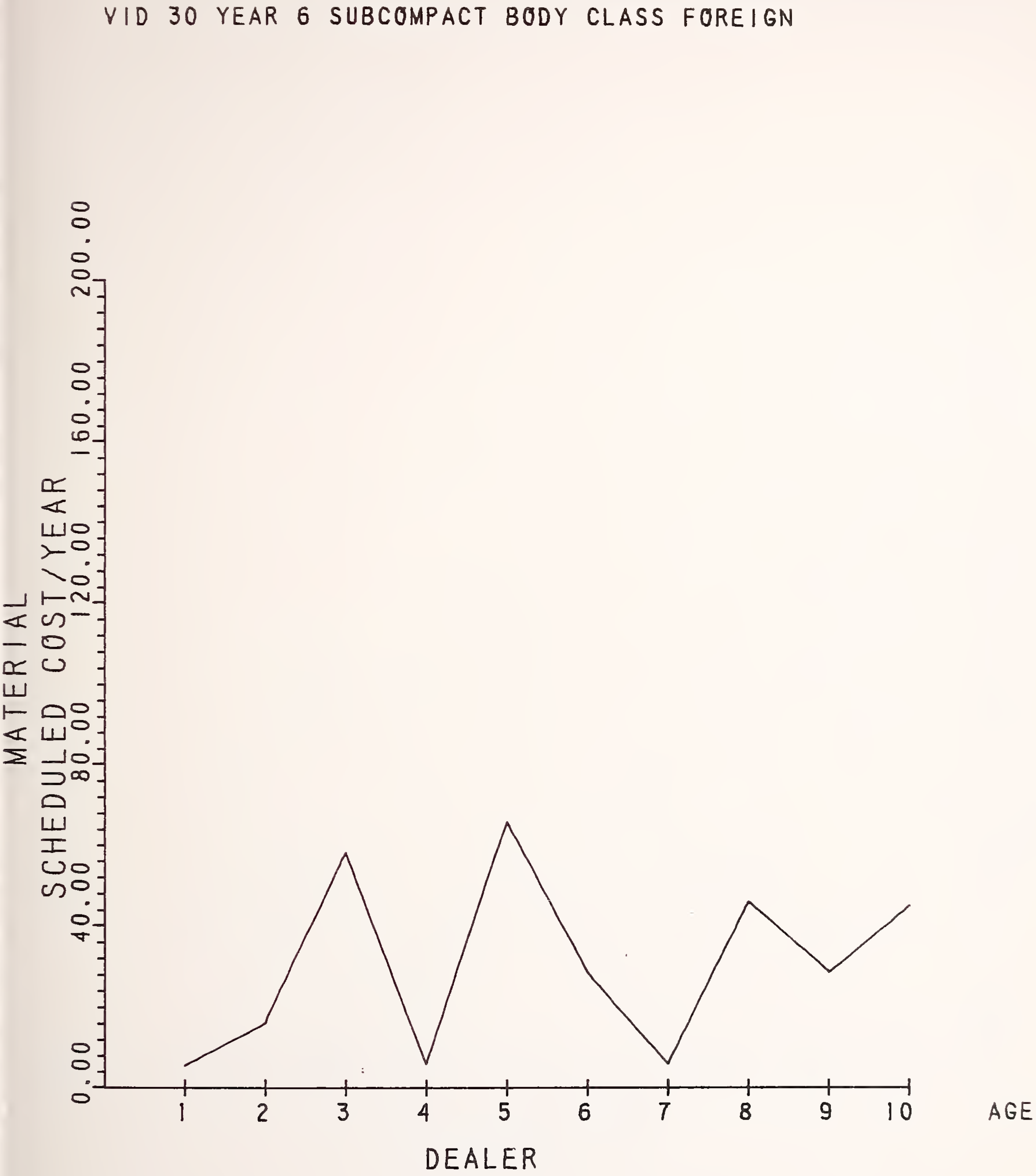

VID 30 YEAR 6 SUBCOMPACT BODY CLASS FOREIGN
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-6

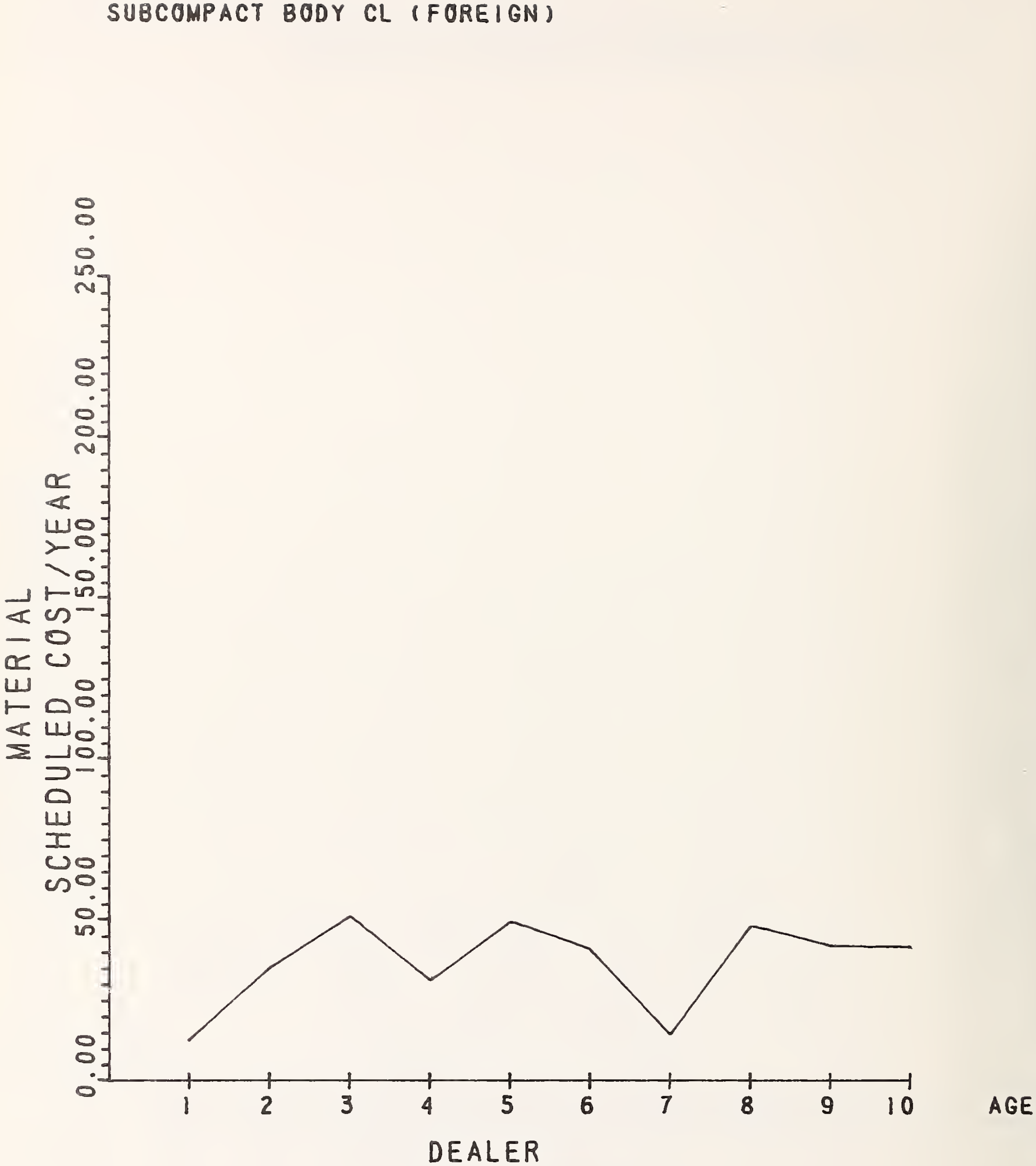

SUBCOMPACT BODY CL (FOREIGN)
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-7

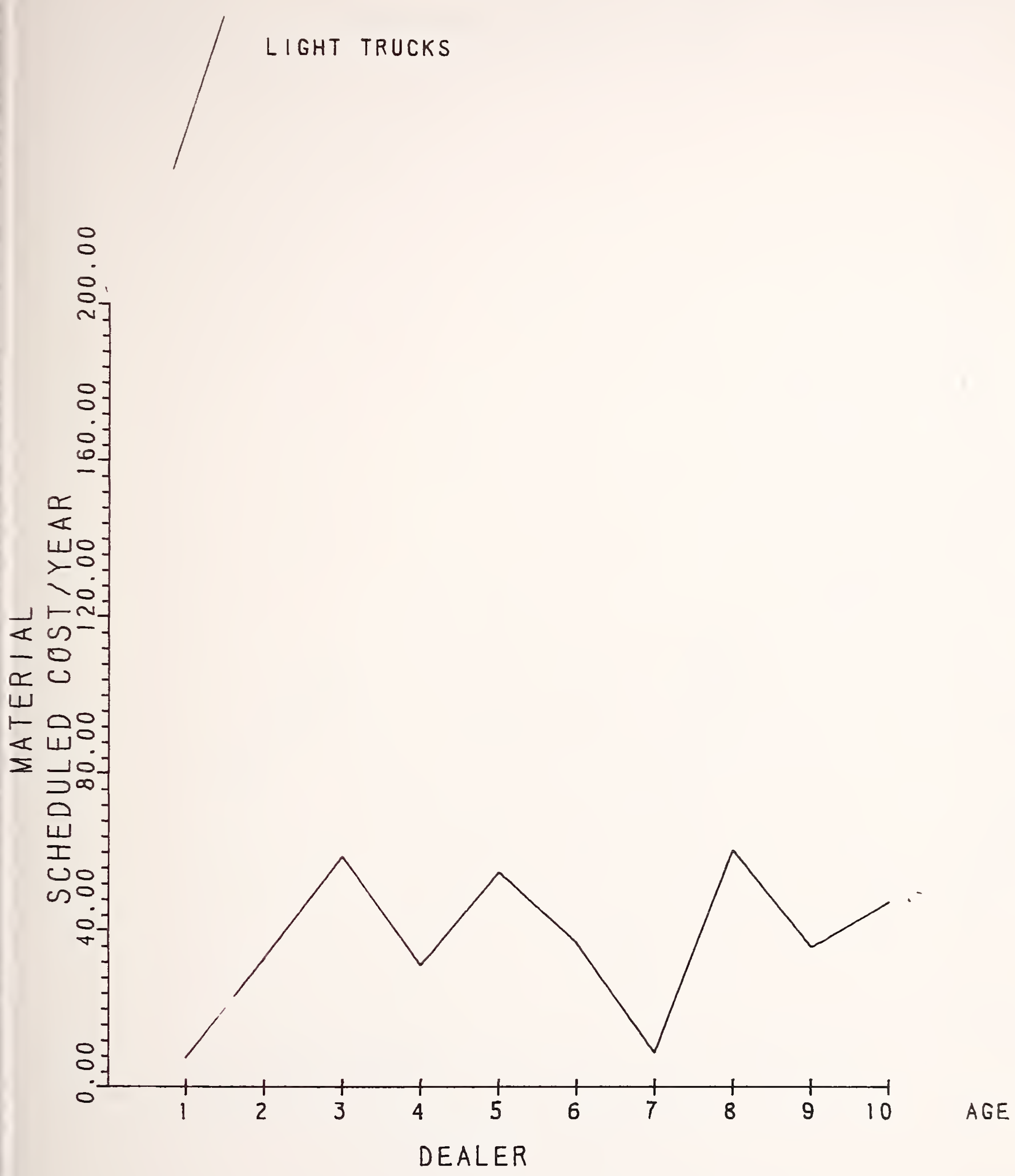

LIGHT TRUCKS
MATERIAL
SCHEDULED CØST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-8

VID BET 1 4 YEAR LT 7 LUXURY BODY CLASS

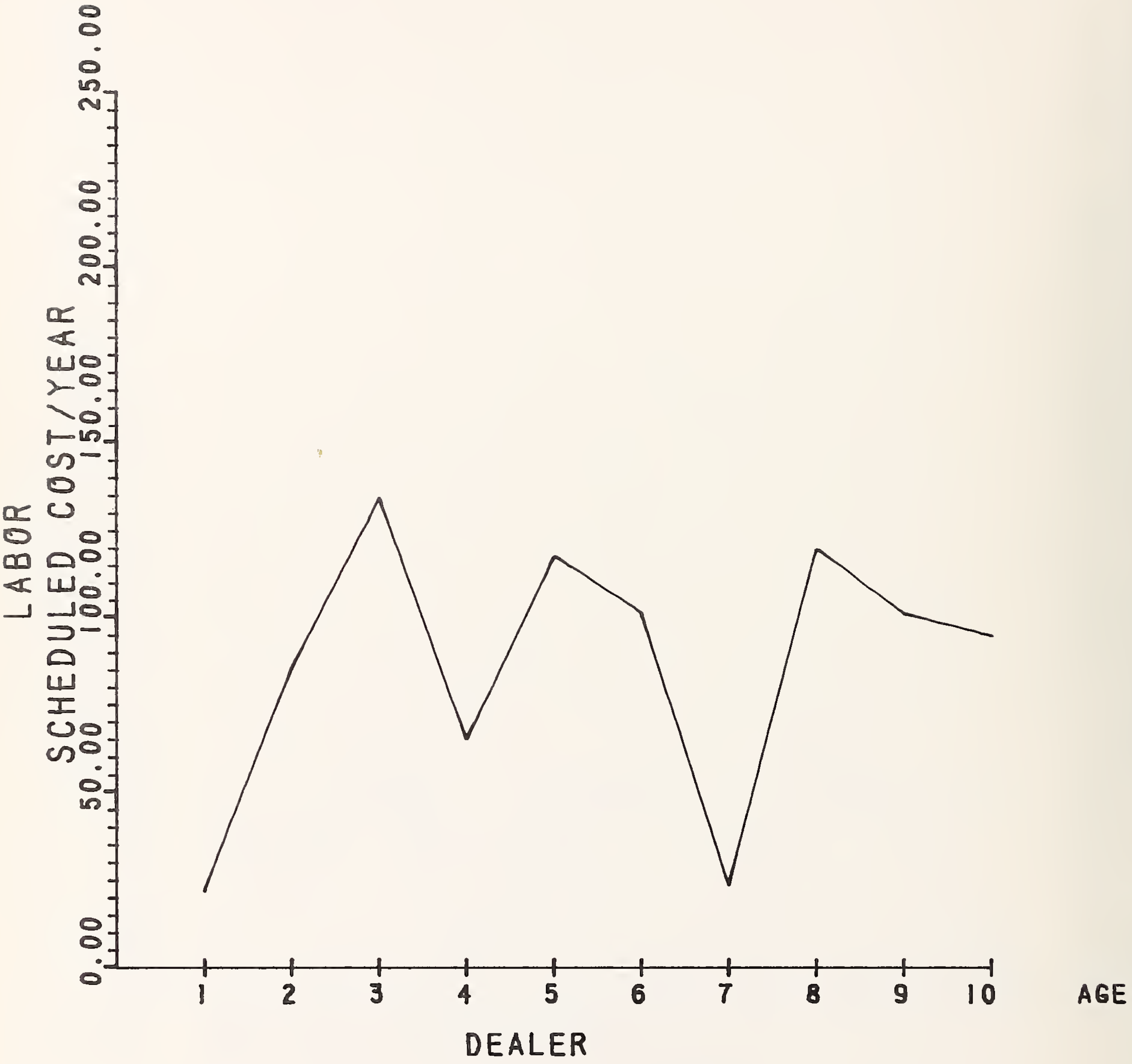


FIGURE A-9

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS

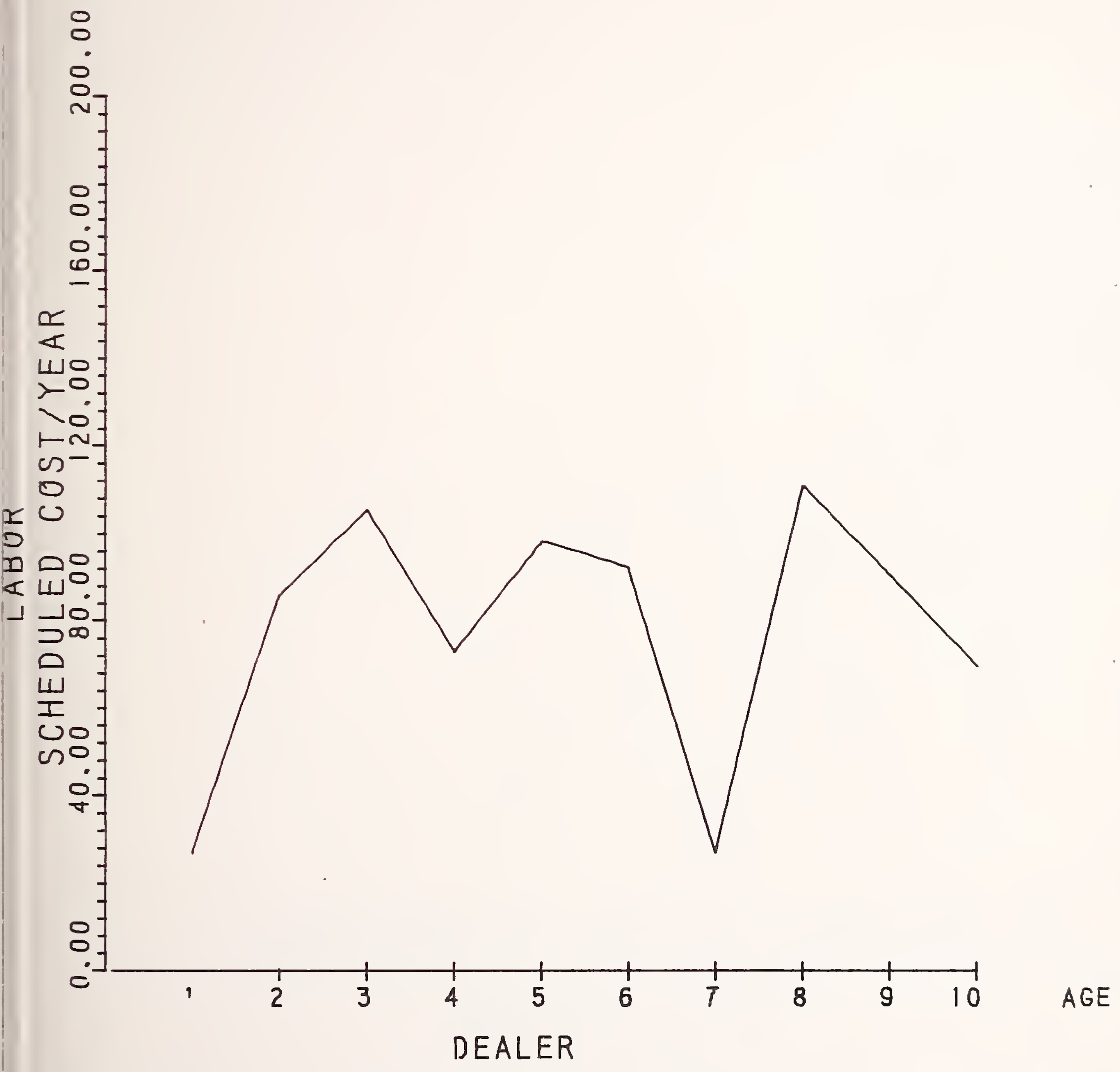


FIGURE A-10

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS

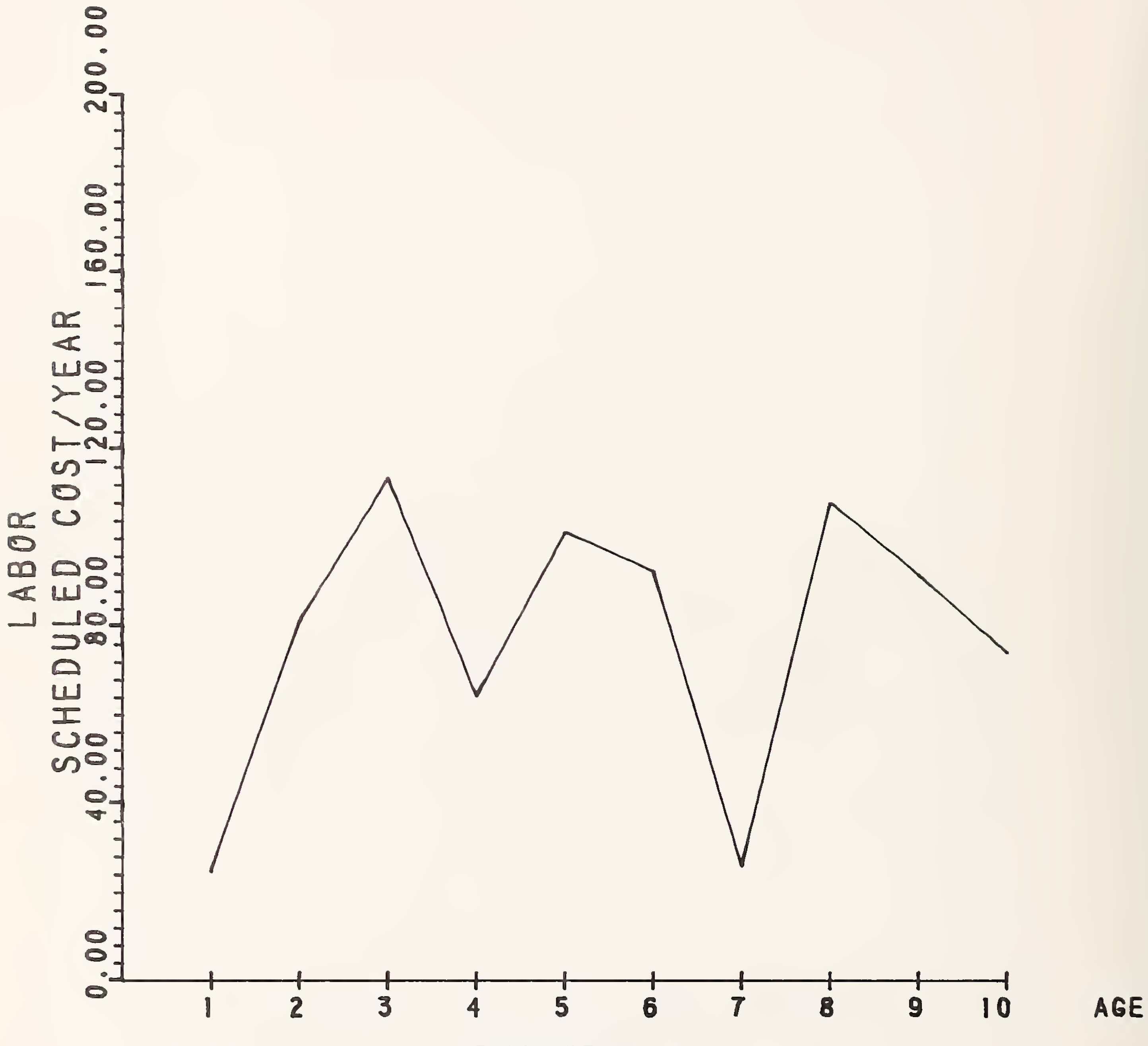


FIGURE A-11

VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS

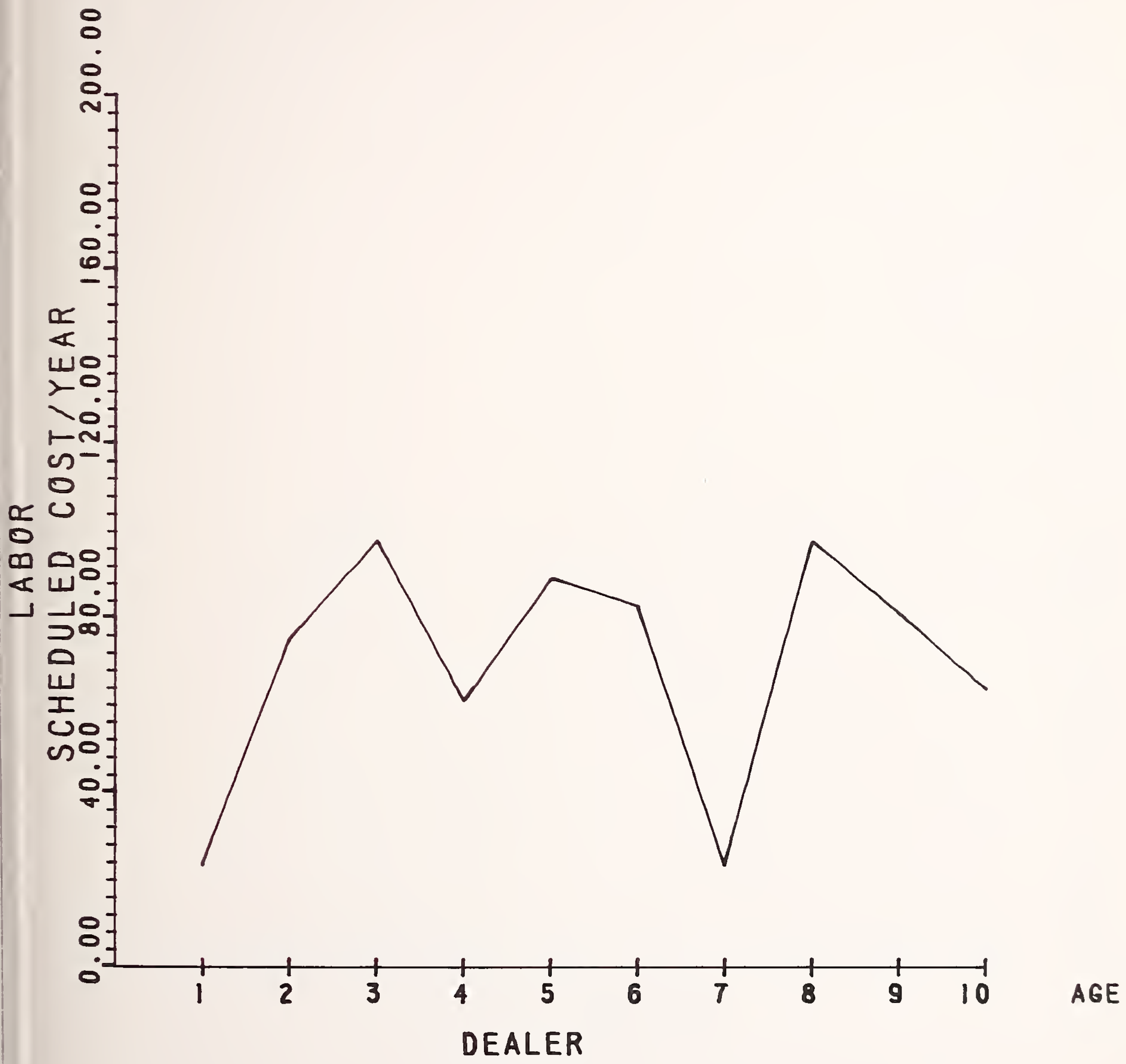


FIGURE A-12

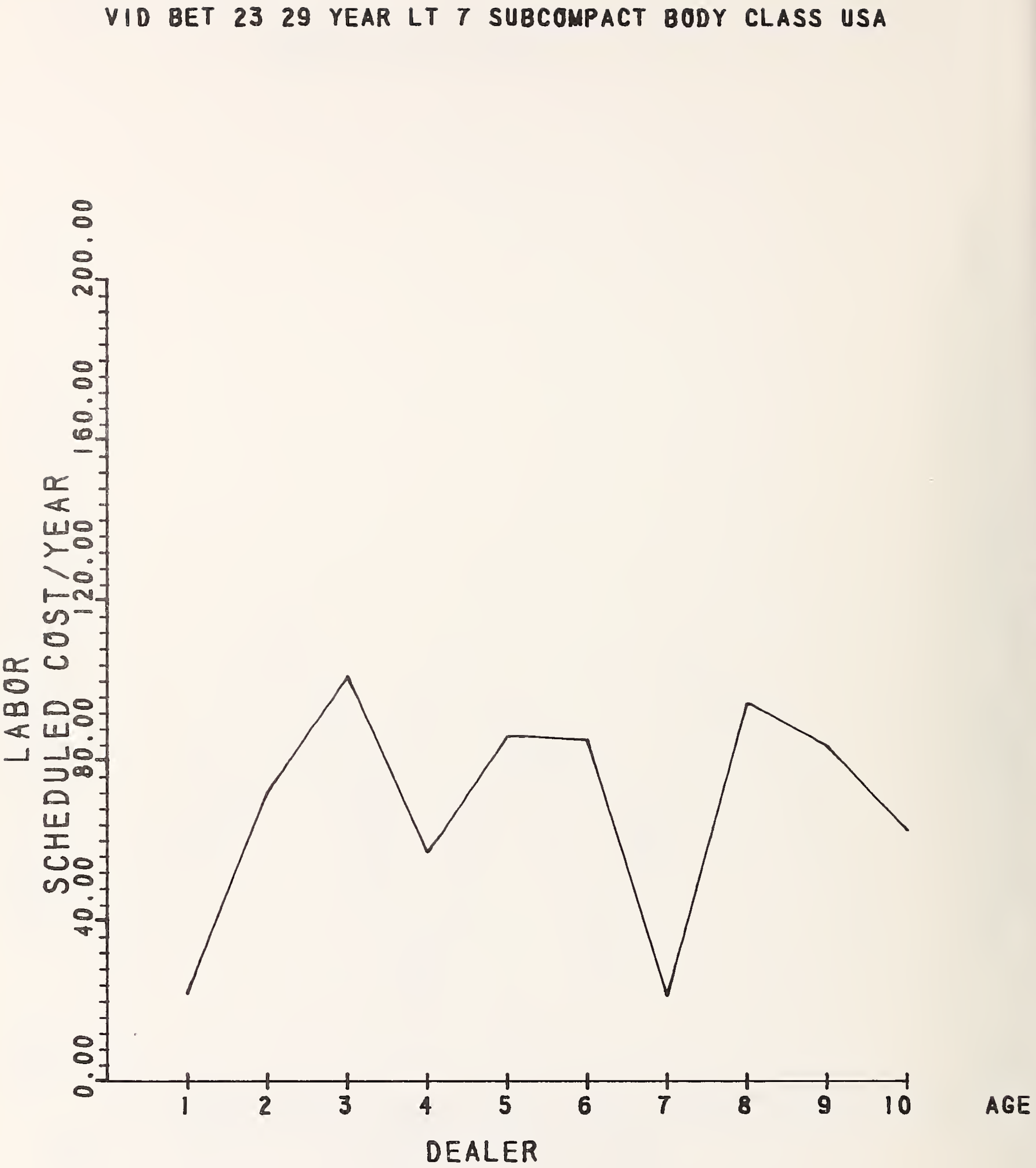

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CLASS USA
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-13

VID 30 YEAR 6 SUBCOMPACT BODY CLASS FOREIGN

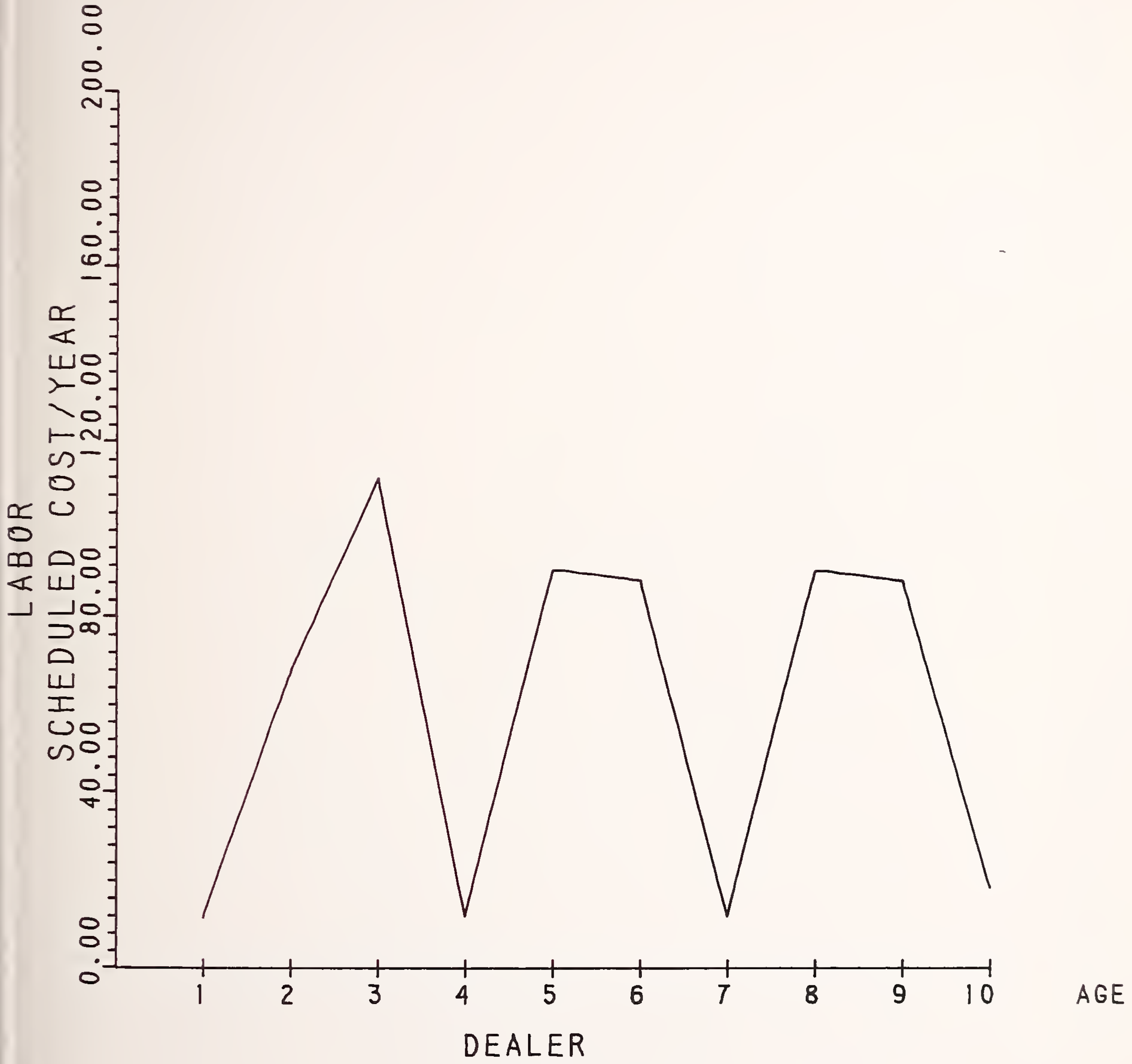


FIGURE A-14

SUBCOMPACT BODY CL (FOREIGN)

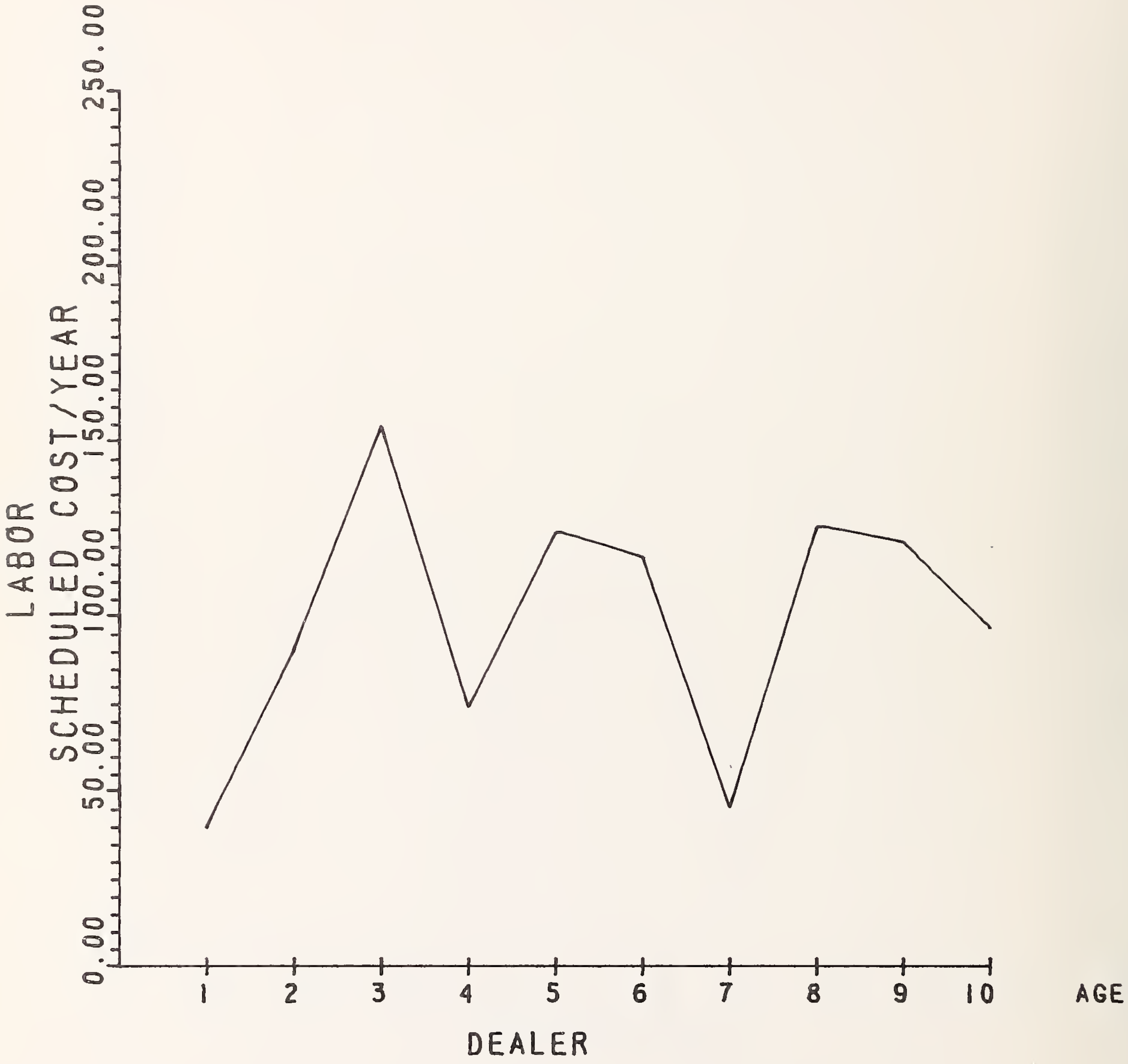


FIGURE A-15

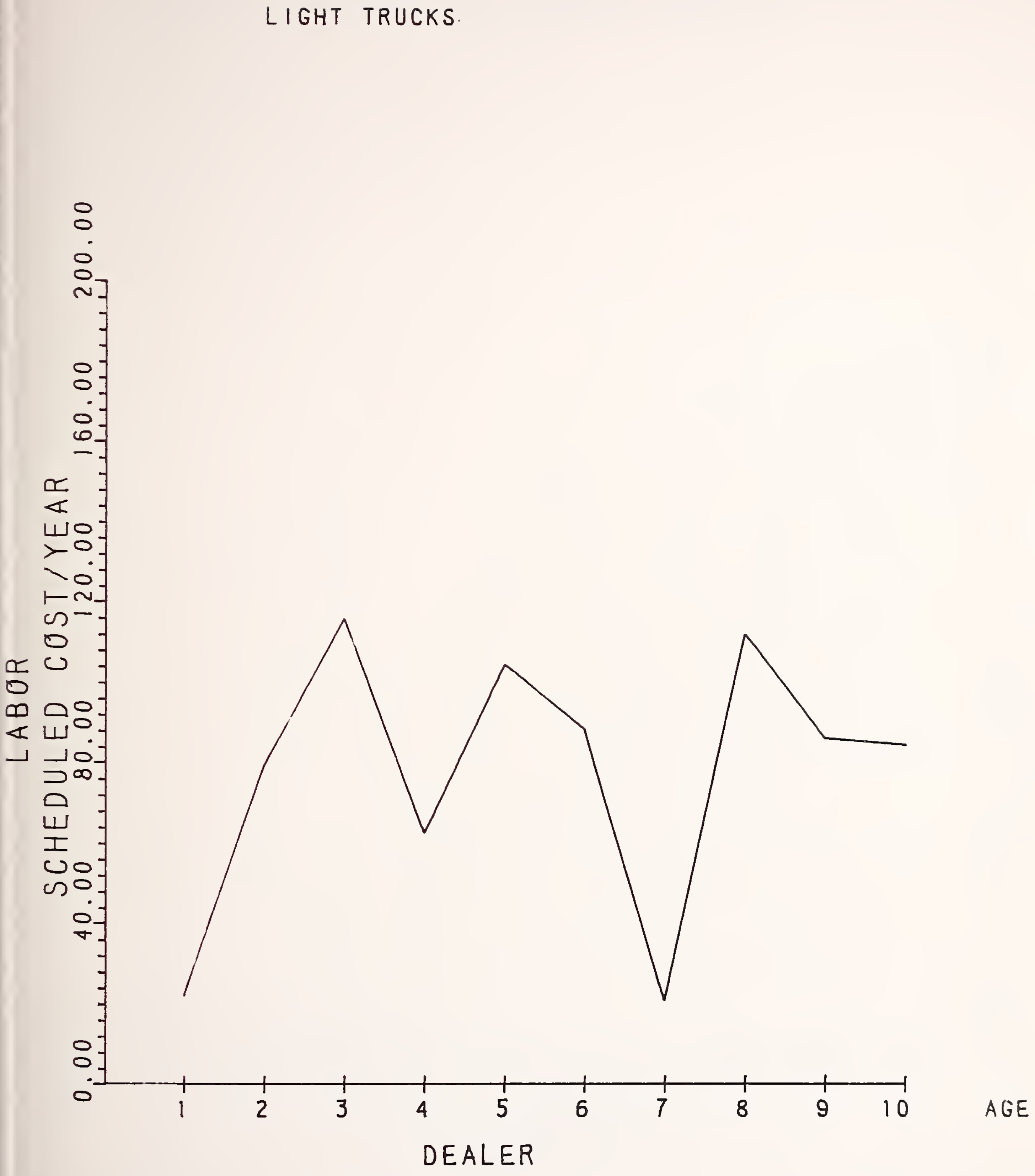

LIGHT TRUCKS
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-16

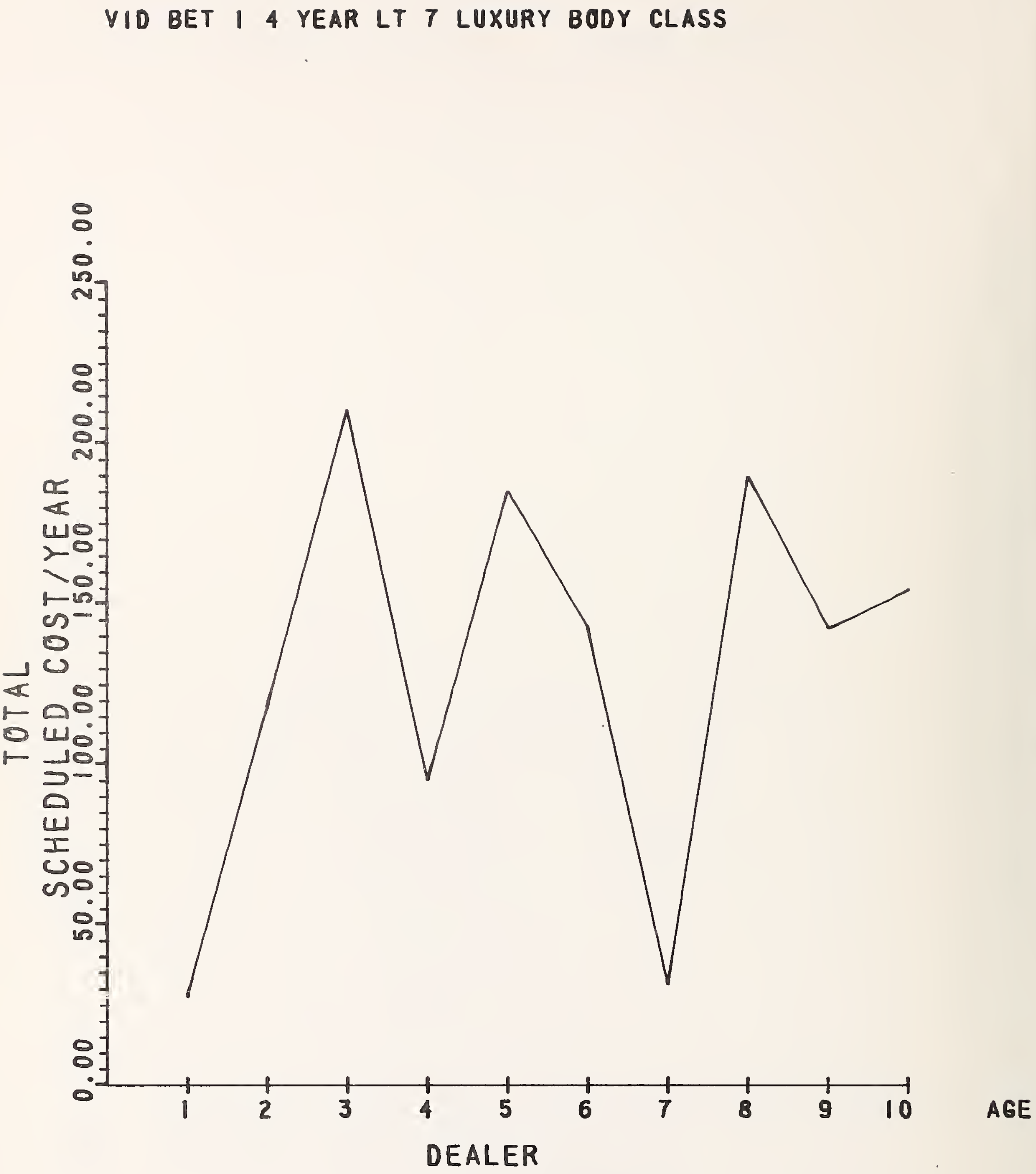

VID BET 1 4 YEAR LT 7 LUXURY BODY CLASS
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-17

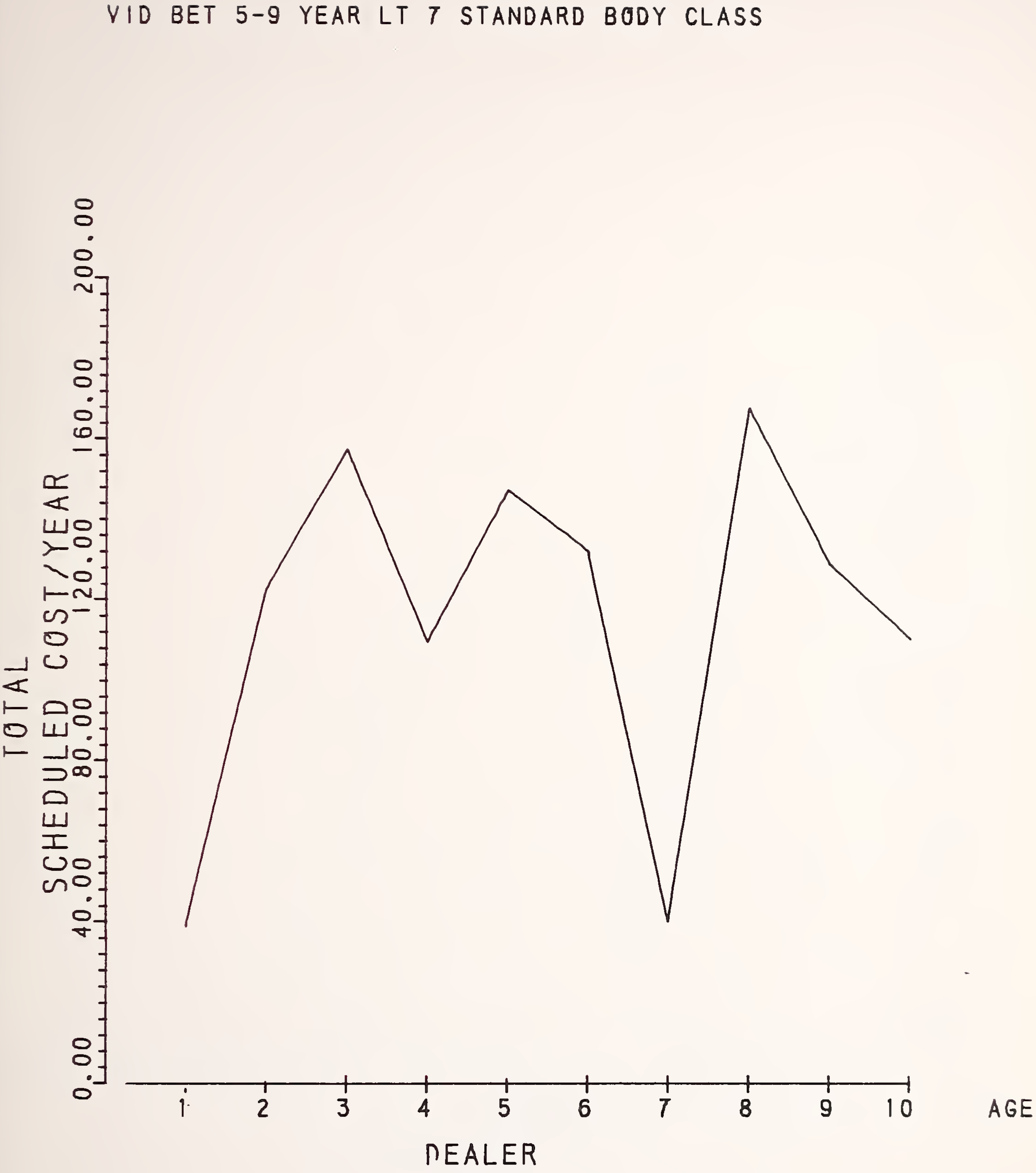

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-18

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS

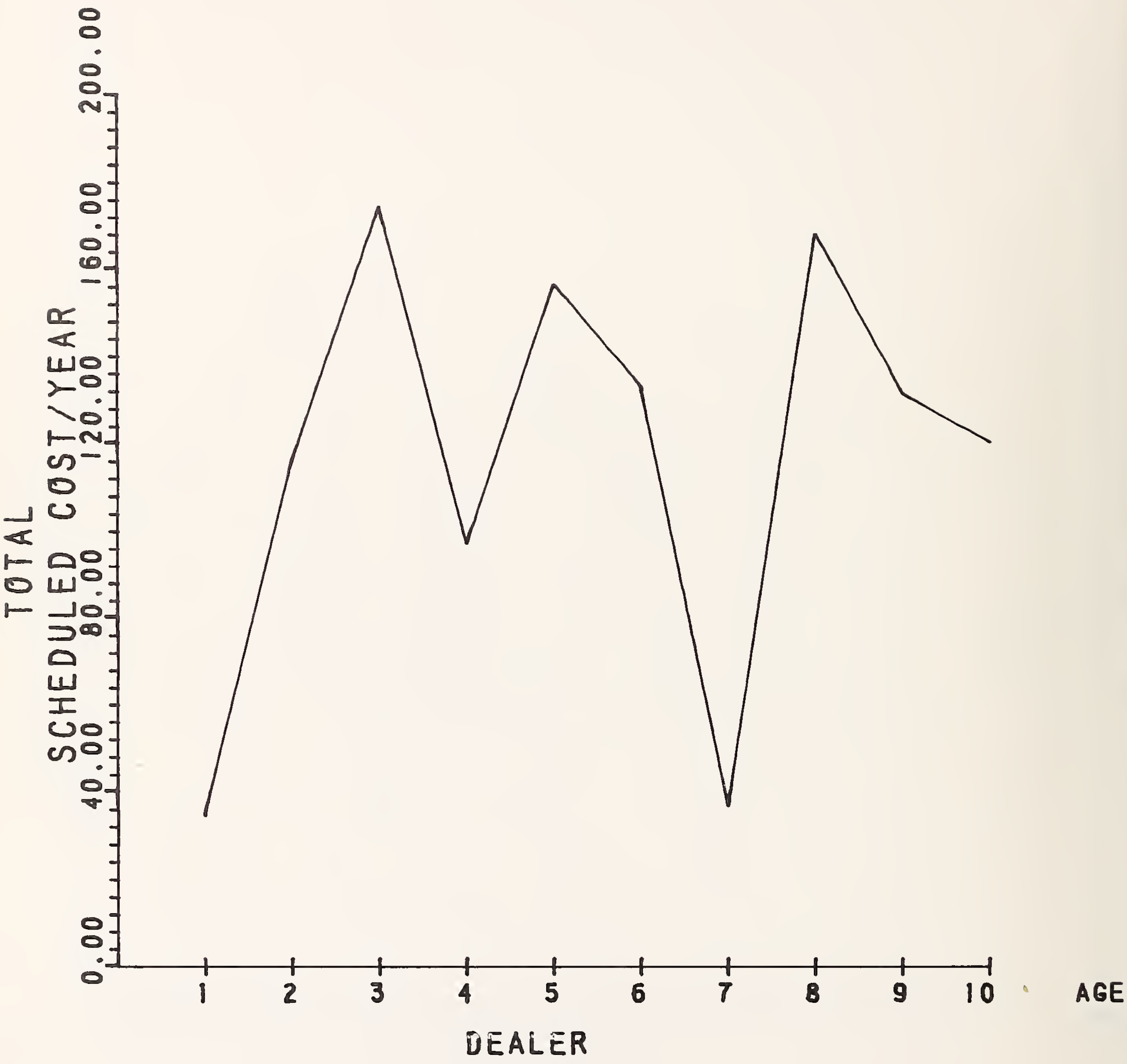


FIGURE A-19

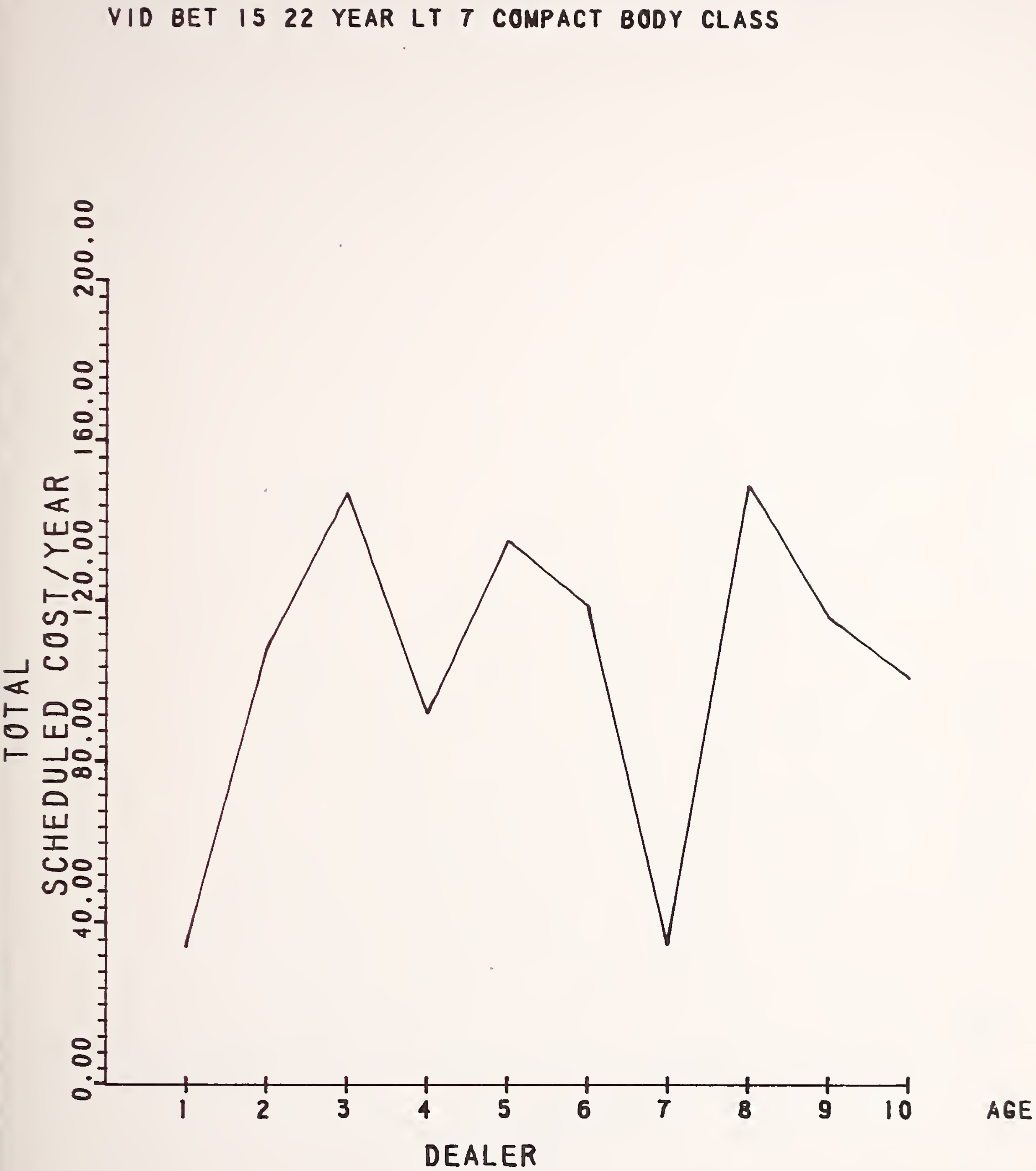

VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS

FIGURE A-20

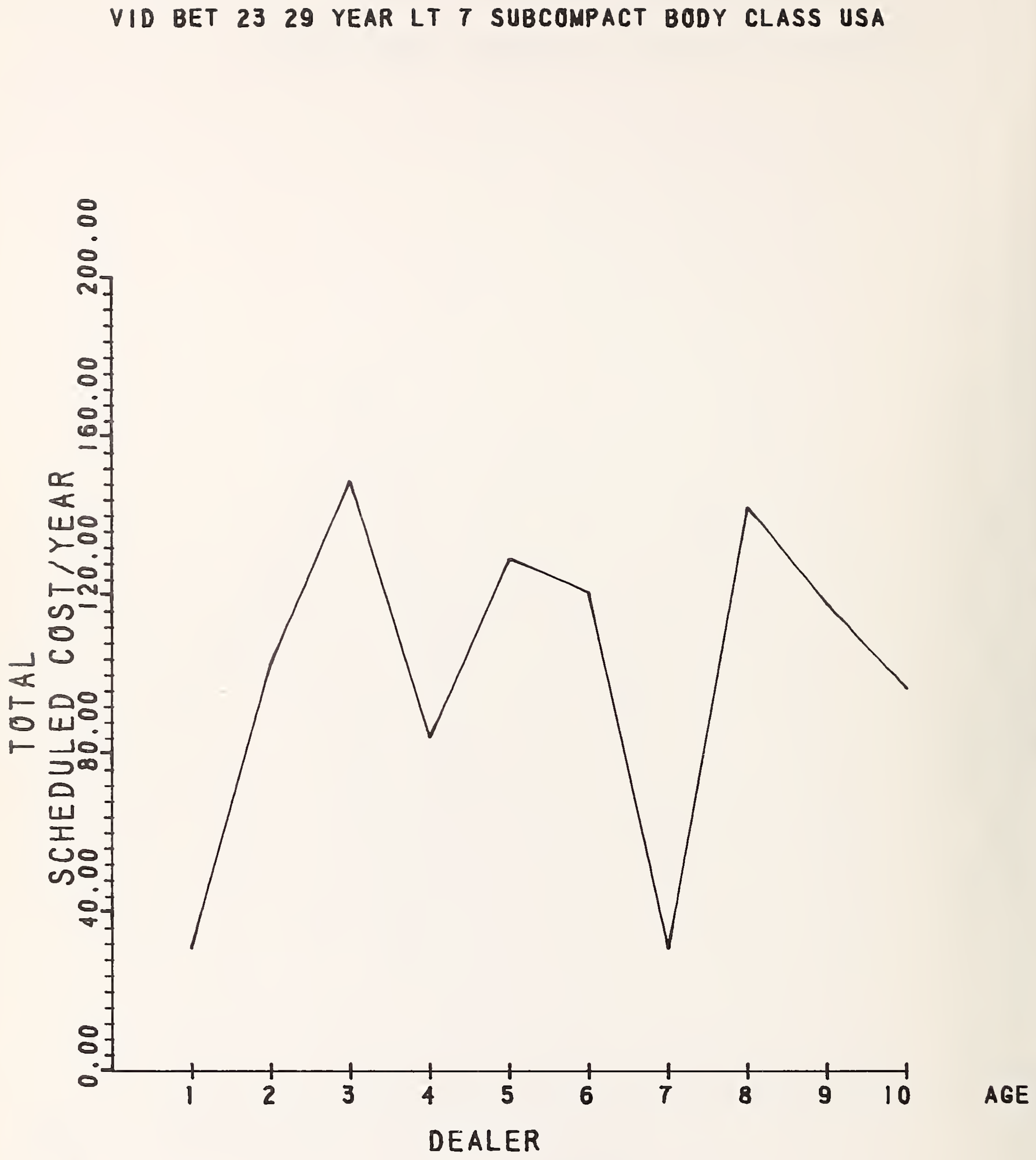

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CLASS USA
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-21

VID 30 YEAR 6 SUBCOMPACT BODY CLASS FOREIGN

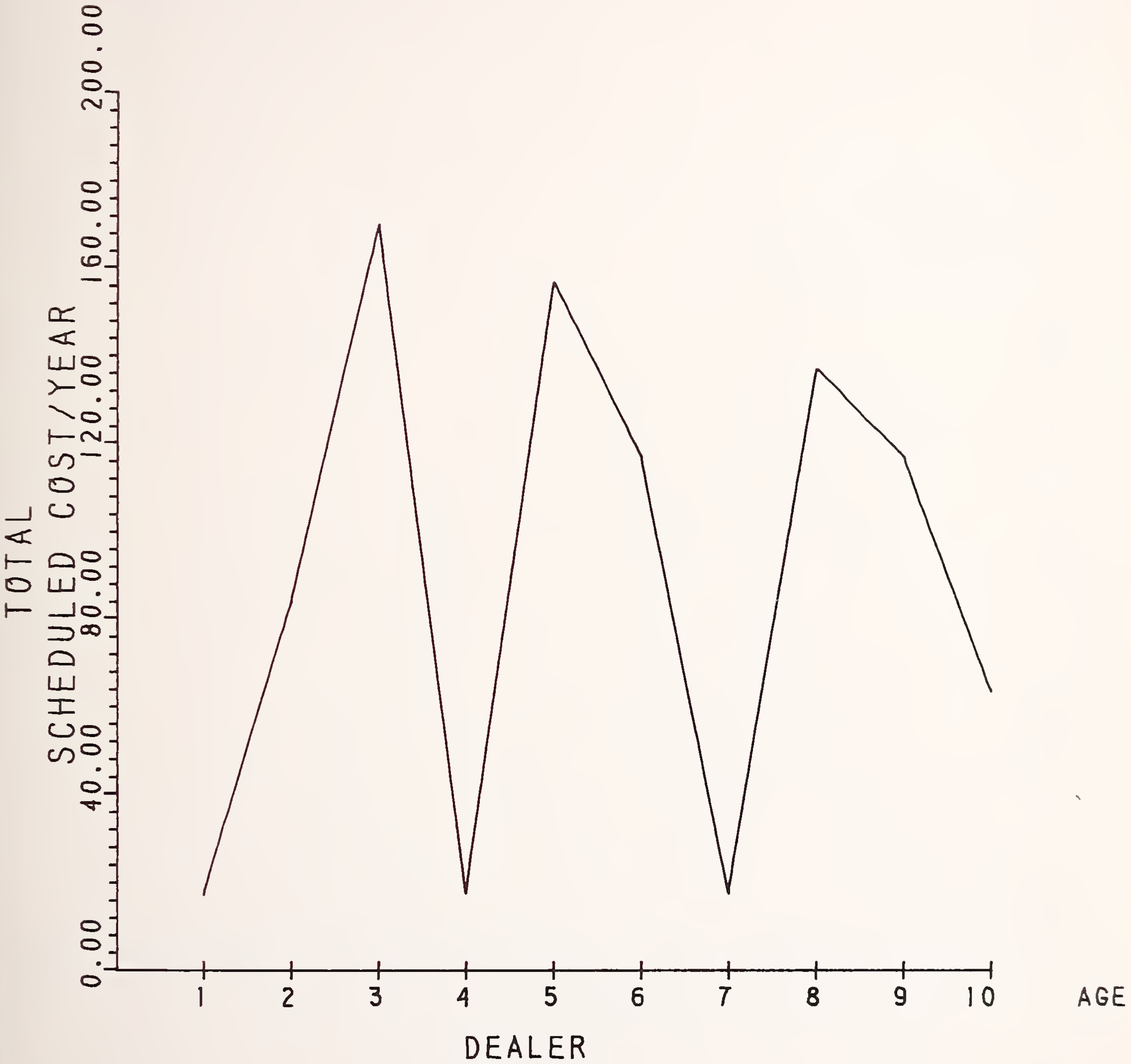


FIGURE A-22

SUBCOMPACT BODY CL (FOREIGN)

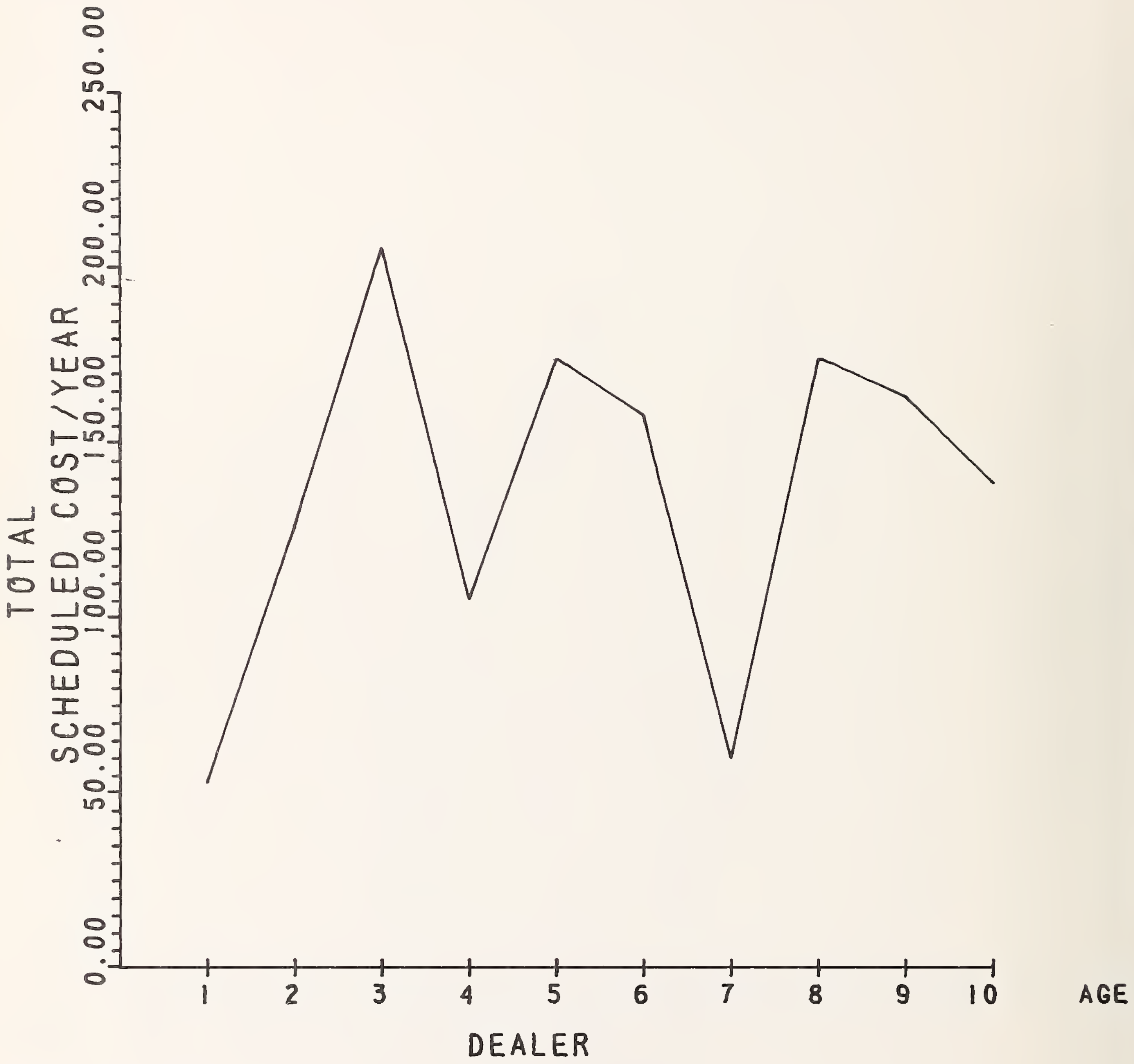


FIGURE A-23

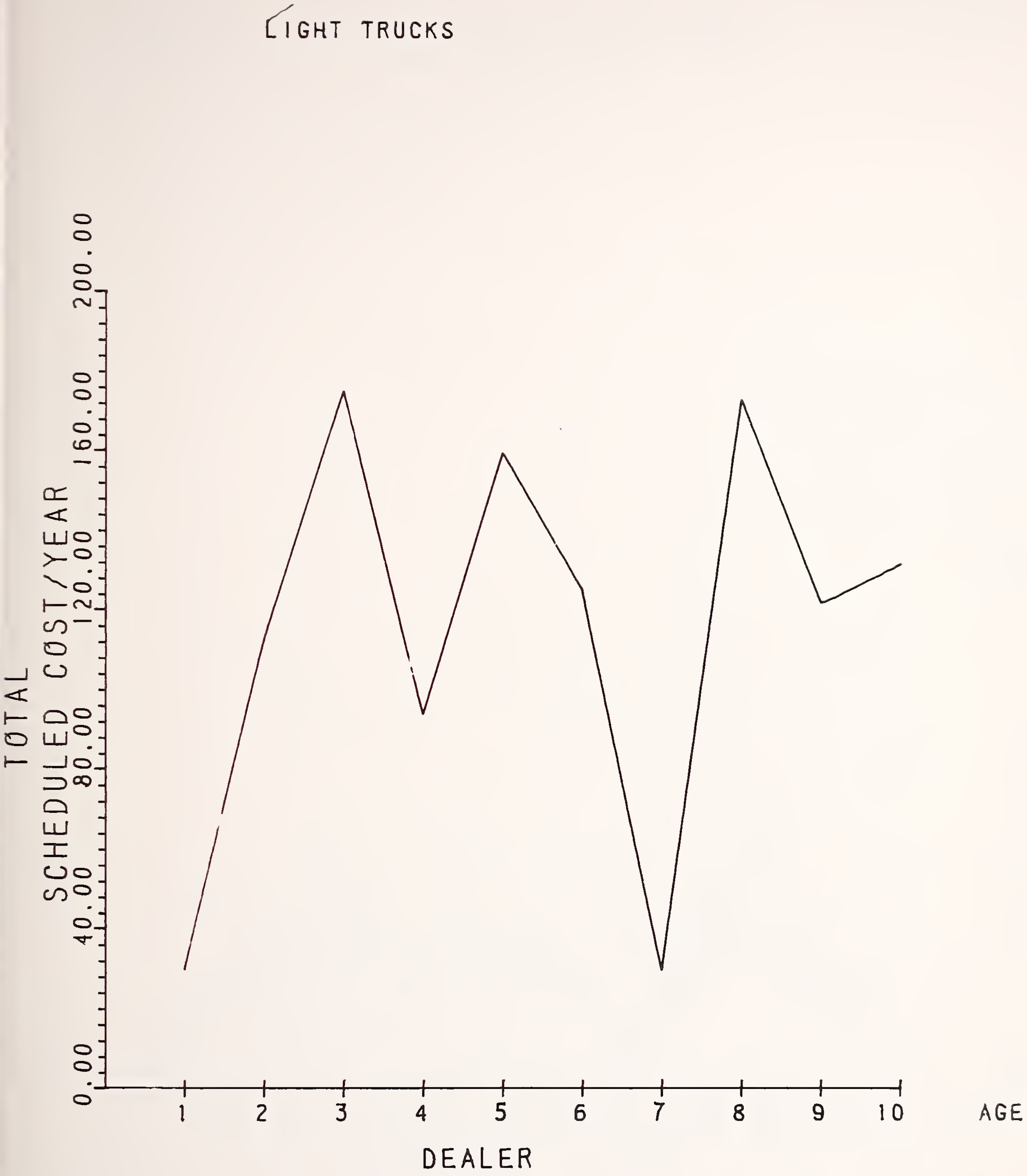

LIGHT TRUCKS
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-24

VID BET 1 4 YEAR LT 7 LUXURY BODY CLASS

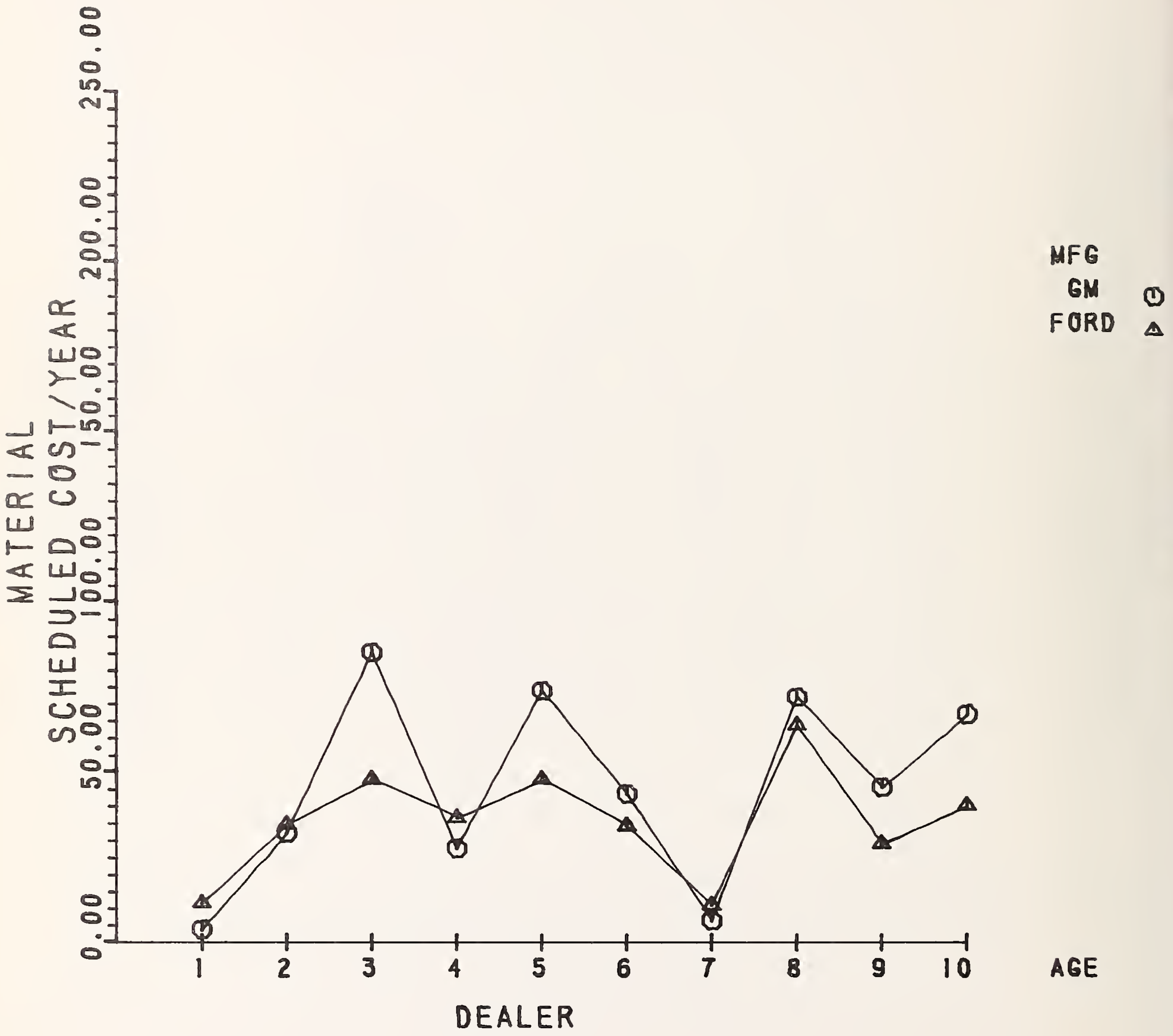


FIGURE A-25

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS

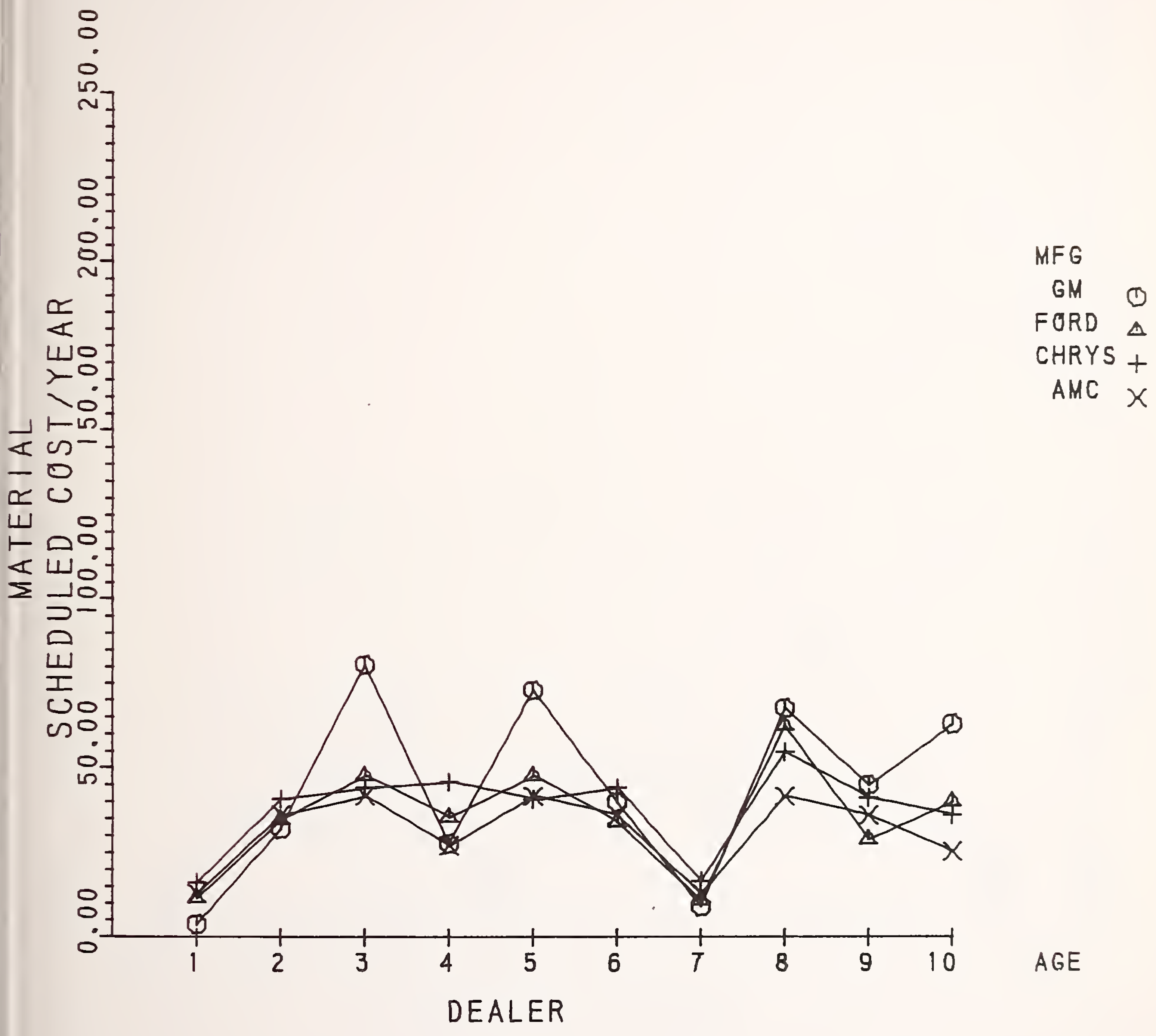


FIGURE A-26

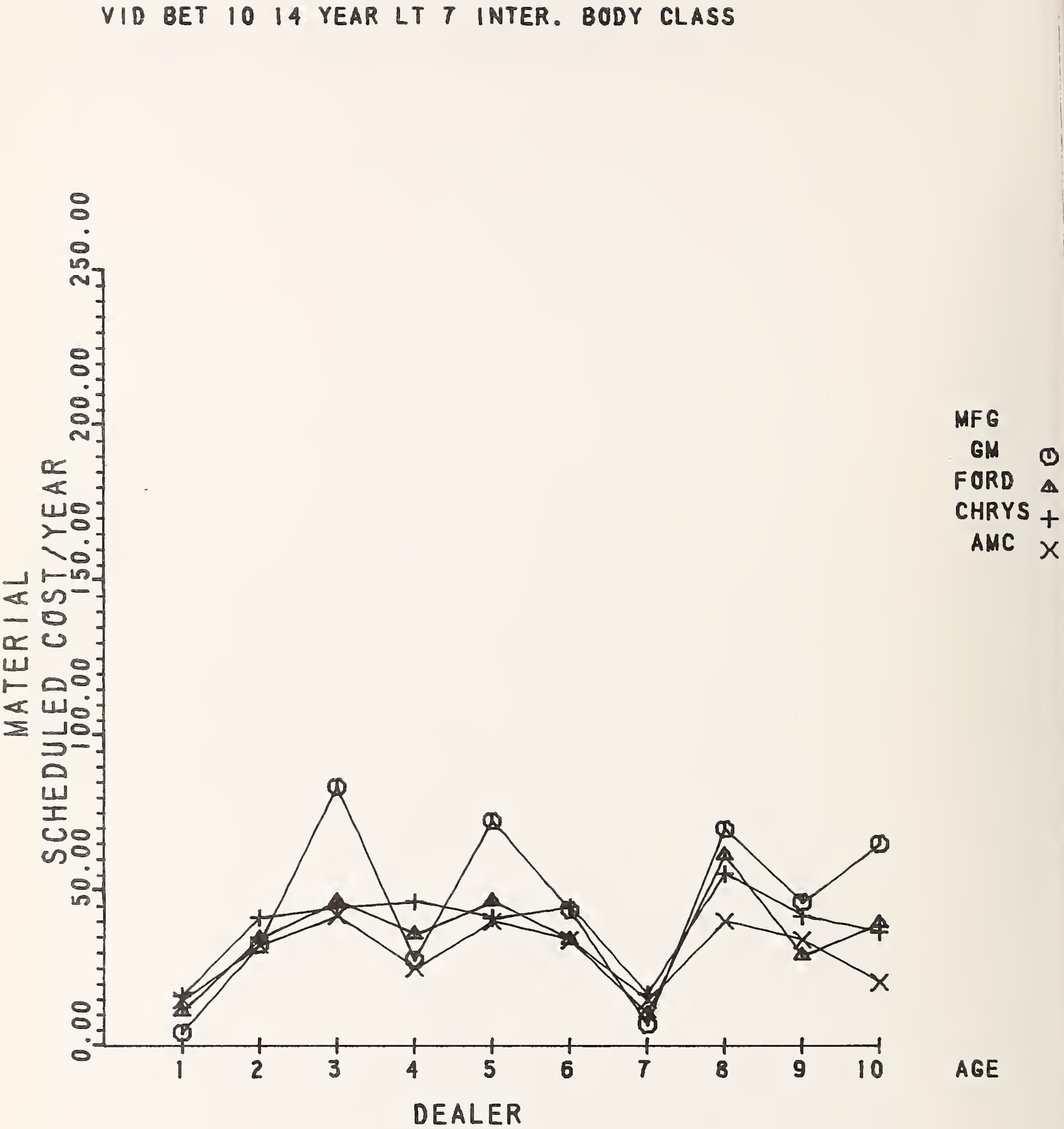

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FORD
CHRYS
AMC

FIGURE A-27

VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS

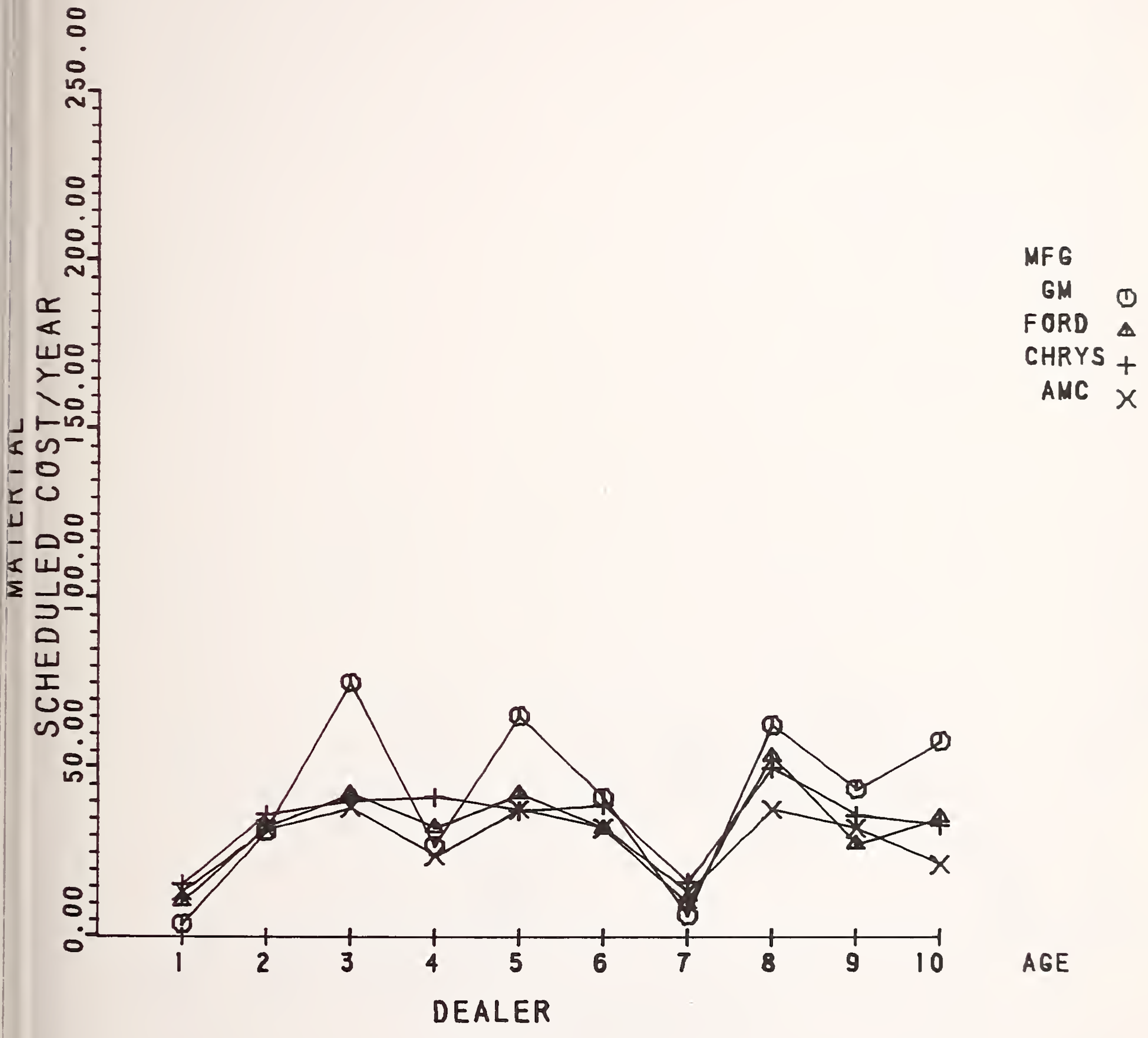


FIGURE A-28

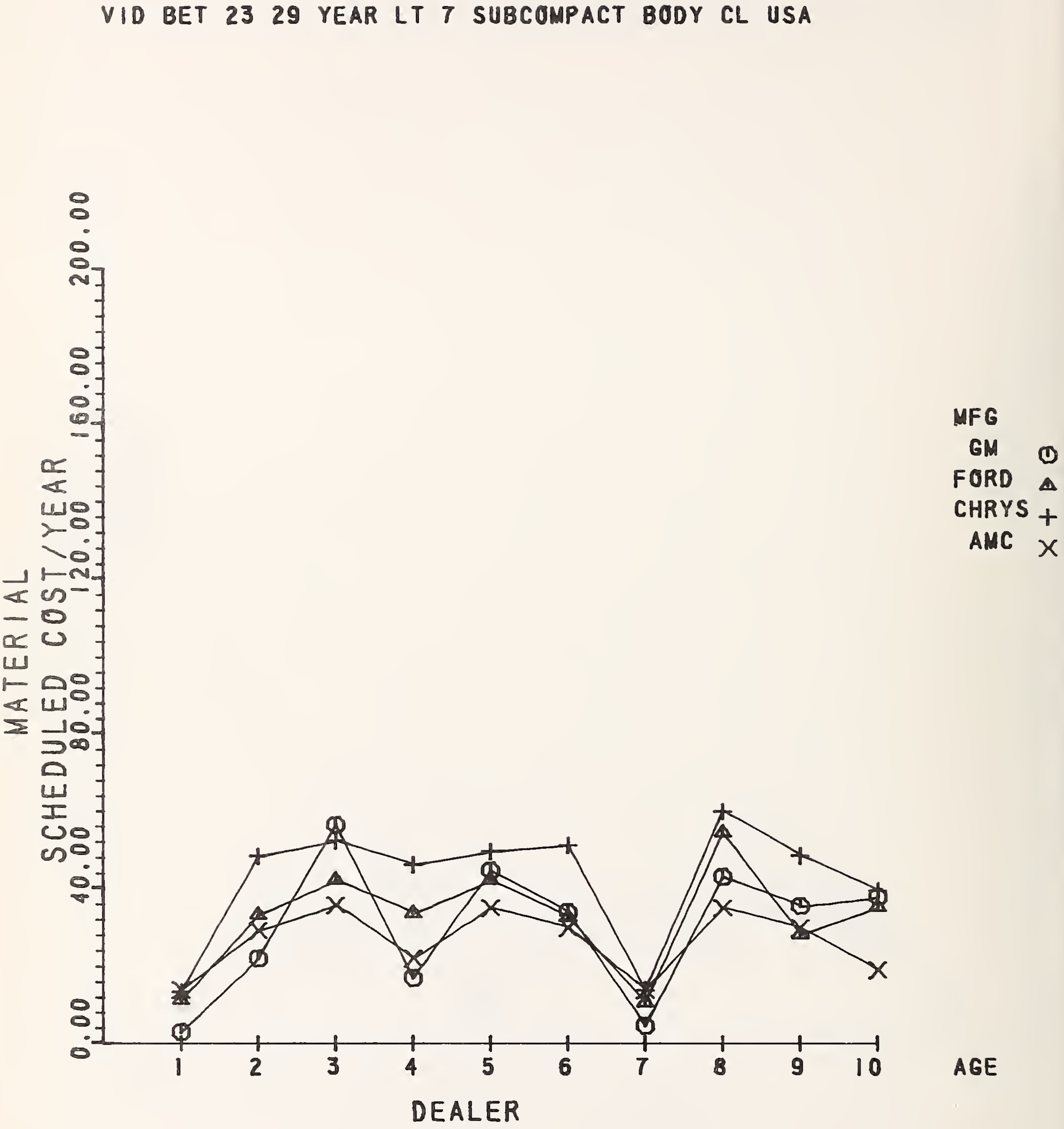

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CL USA
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FORD
CHRYS
AMC

FIGURE A-29

VW 1975

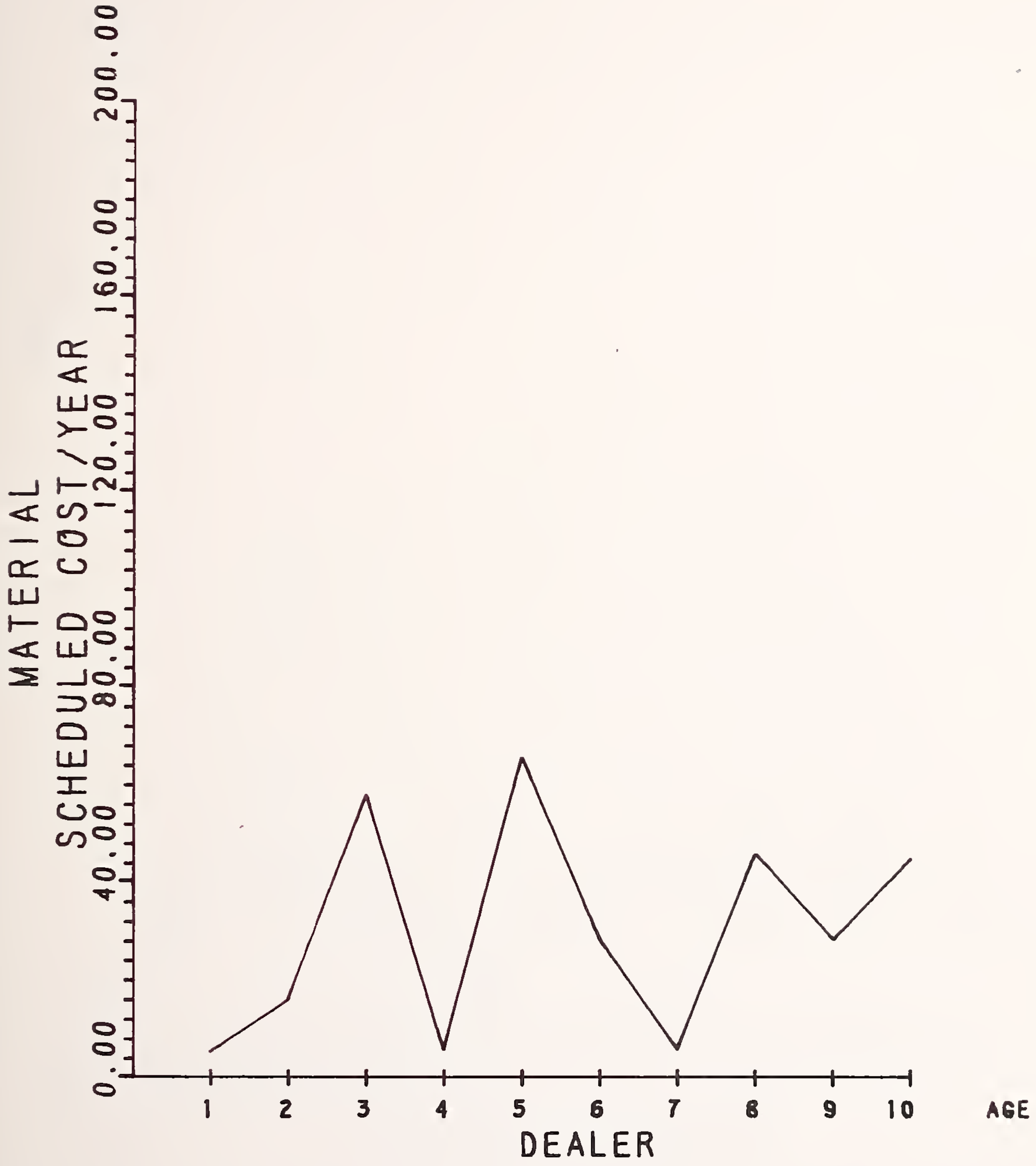


FIGURE A-30

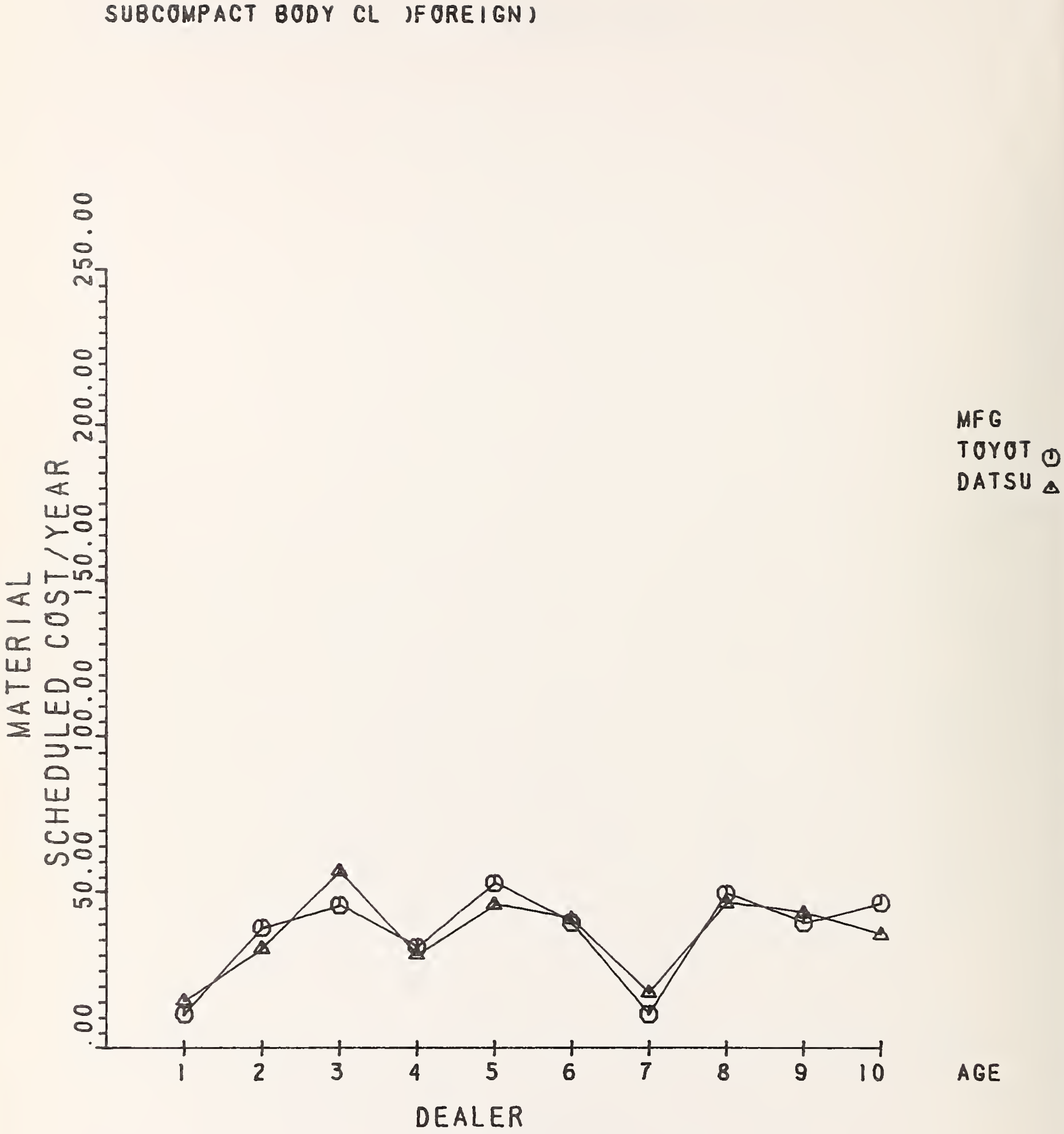

SUBCOMPACT BODY CL)FOREIGN)
MATERIAL
SCHEDULED COST/YEAR
.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
TOYOT ⊕
DATSU △

FIGURE A-31

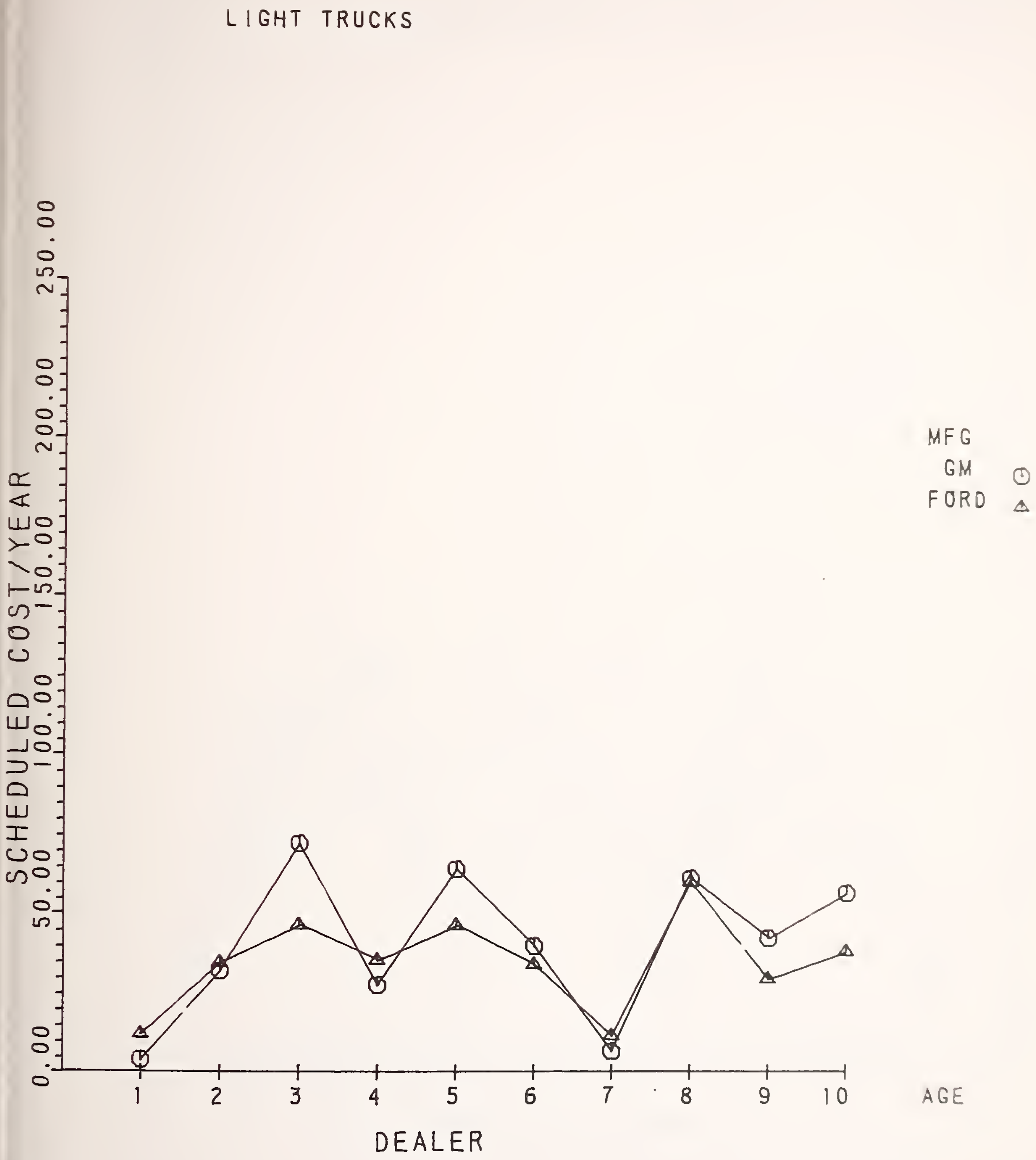

LIGHT TRUCKS
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD

FIGURE A-32

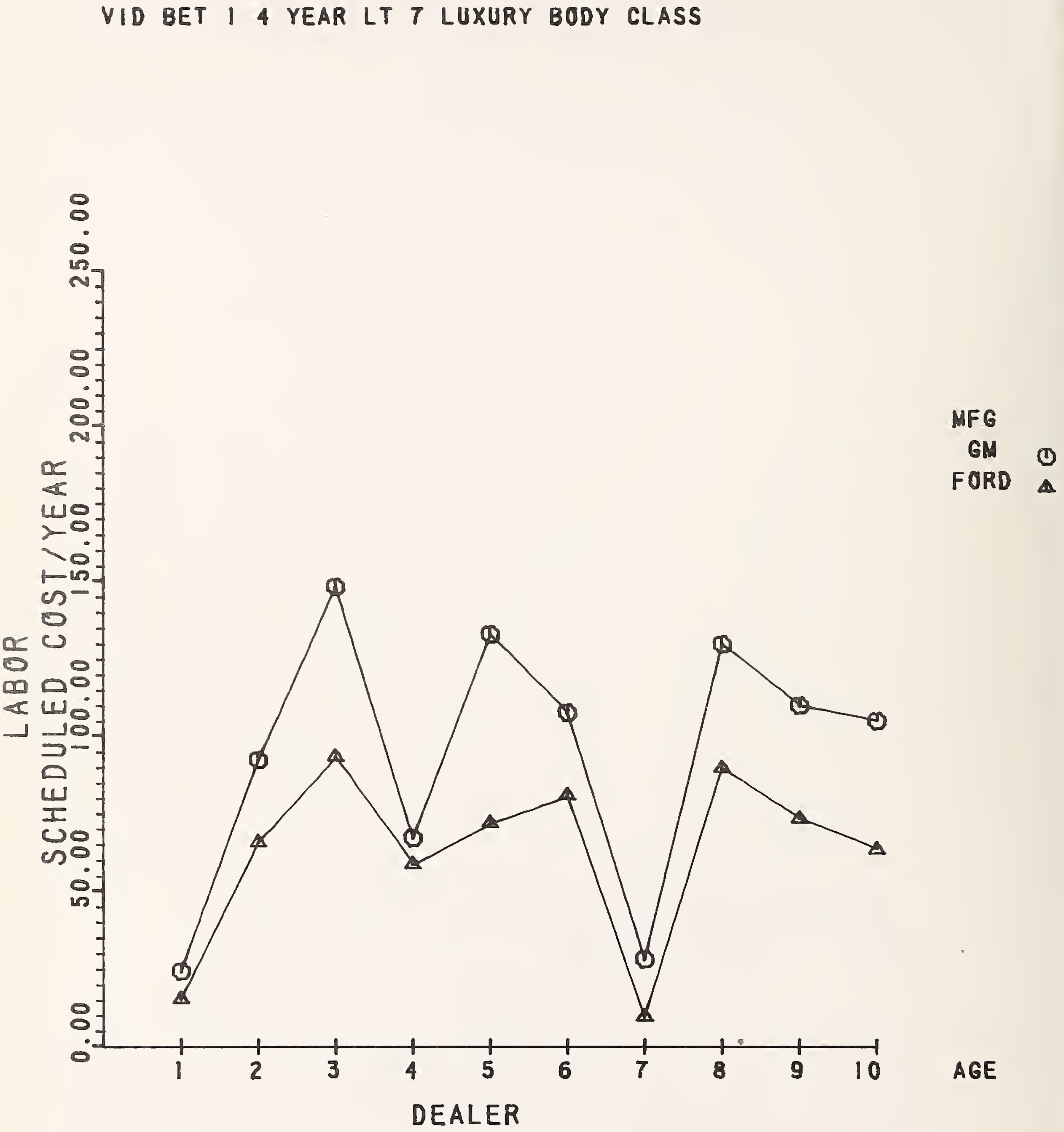

VID BET 1 4 YEAR LT 7 LUXURY BODY CLASS
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
MFG
GM
FORD
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-33

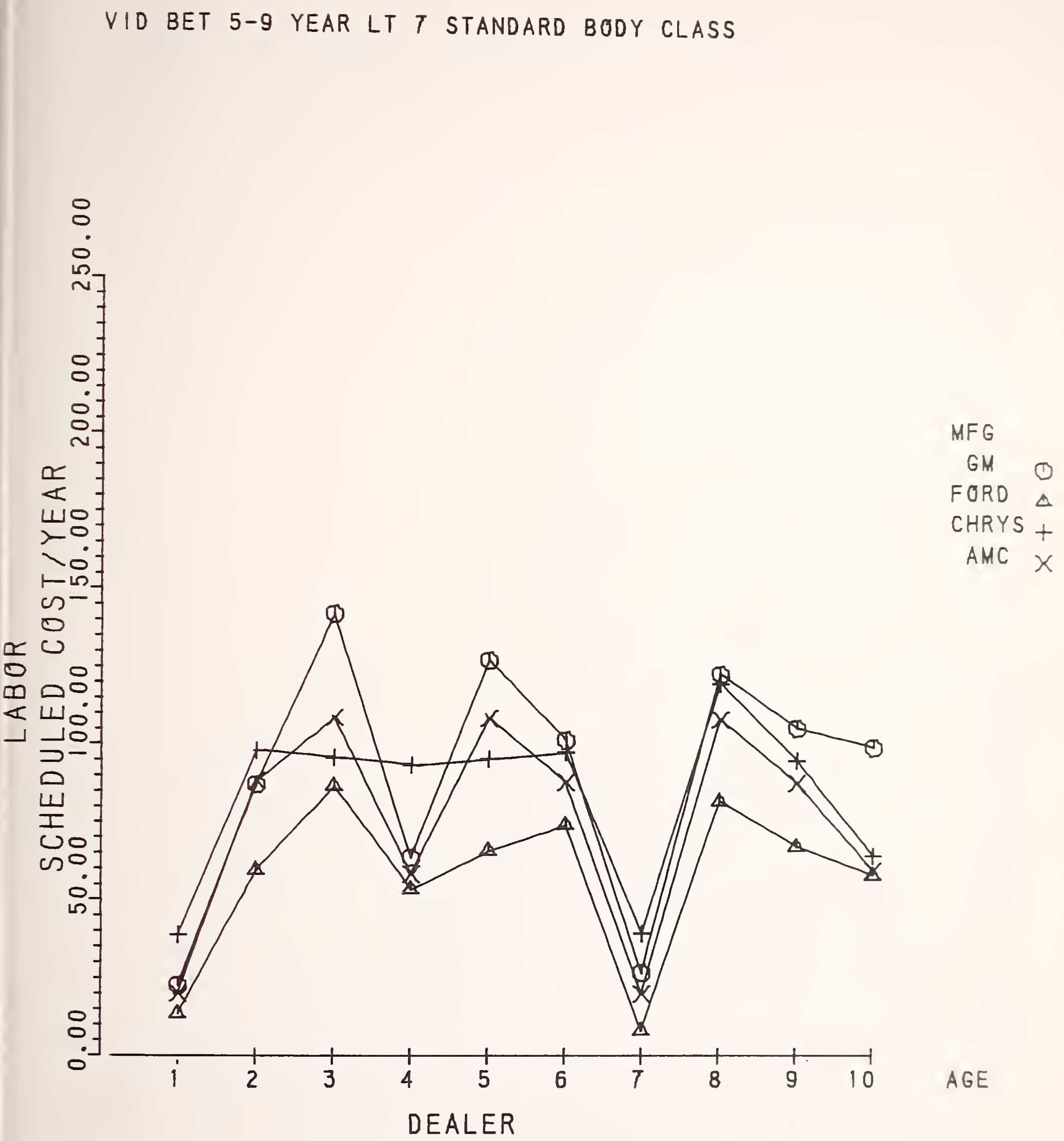

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-34

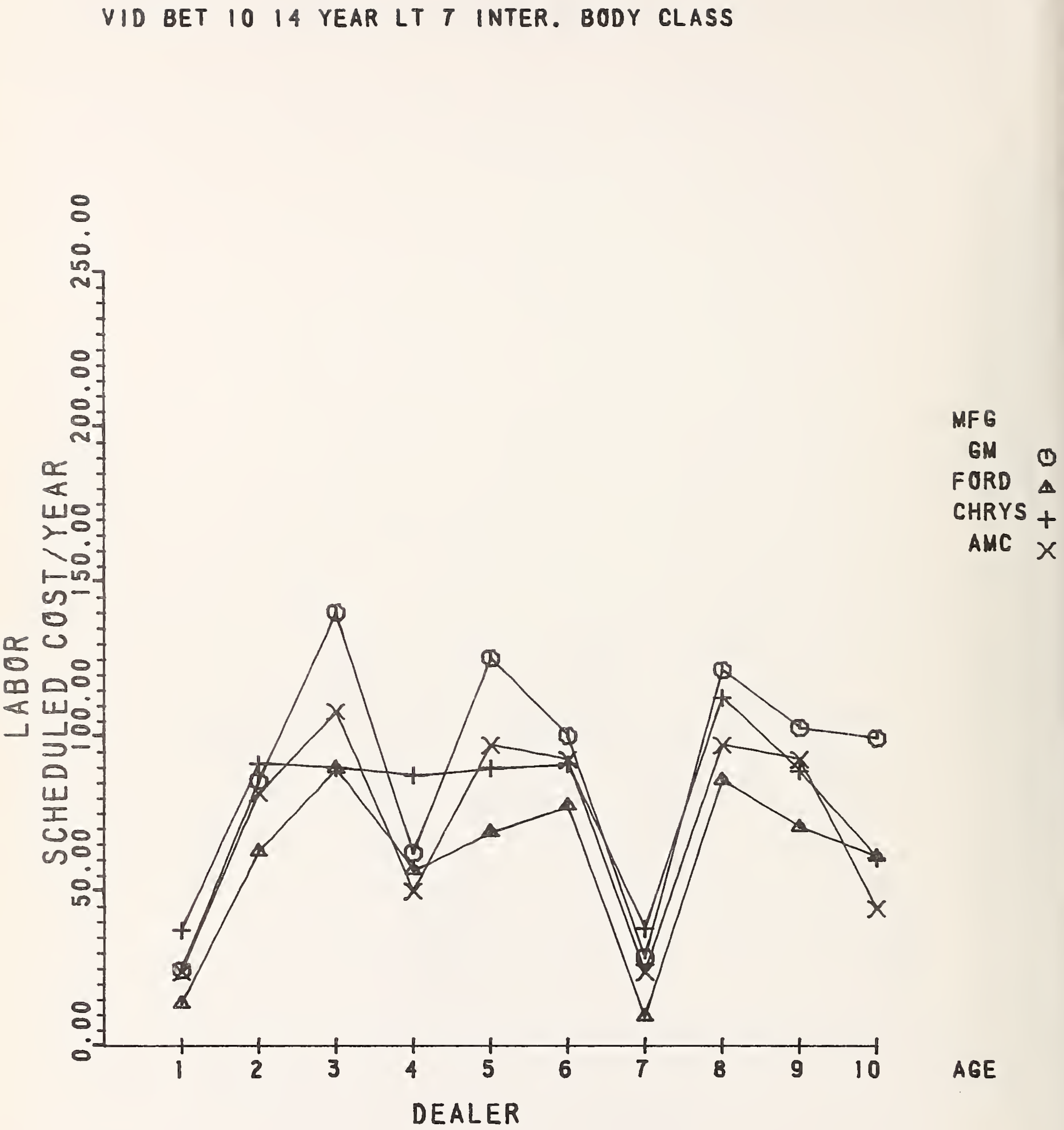

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FORD
CHRYS
AMC

FIGURE A-35

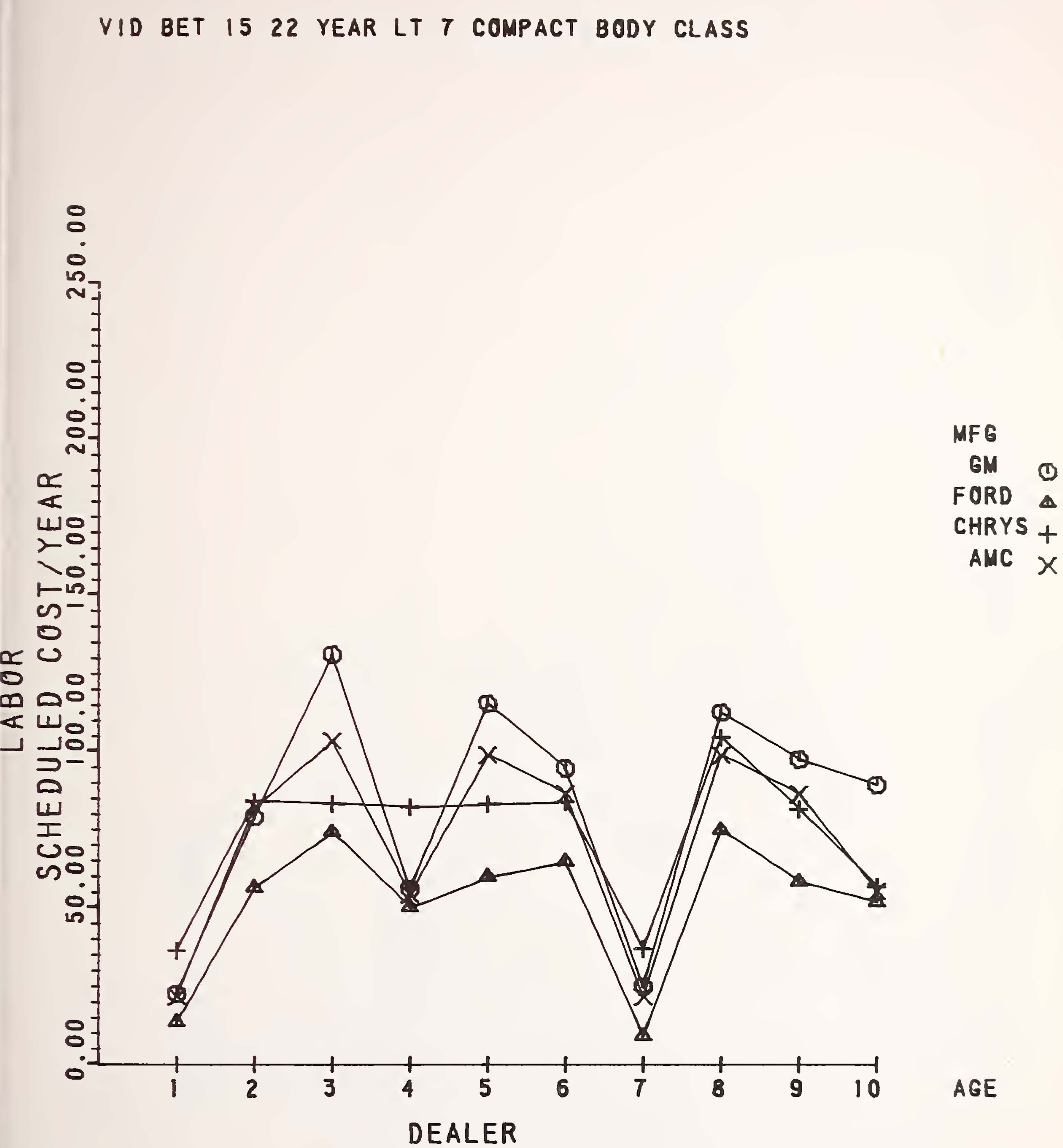

VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-36

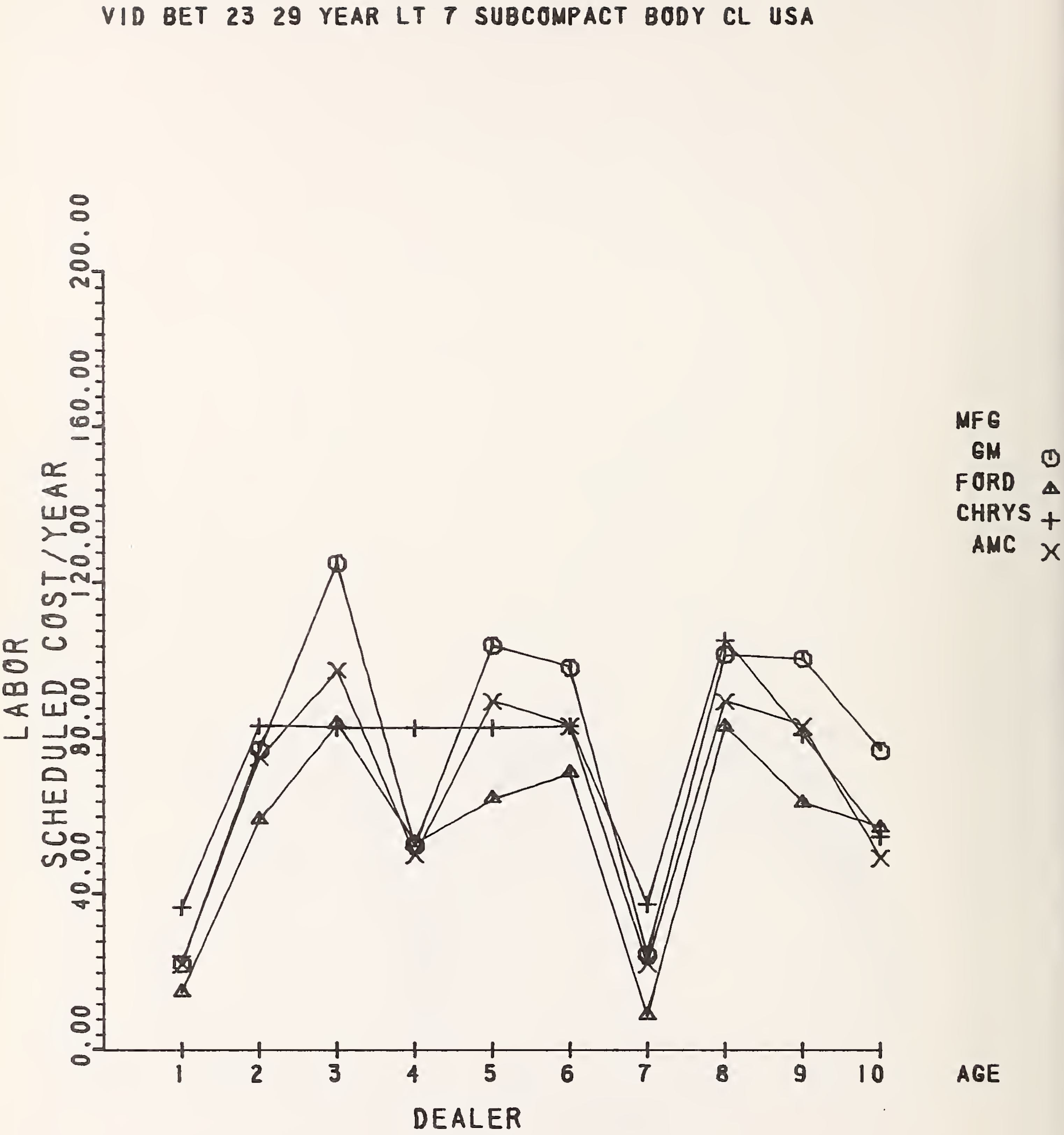

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CL USA
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FØRD
CHRYS
AMC

FIGURE A-37

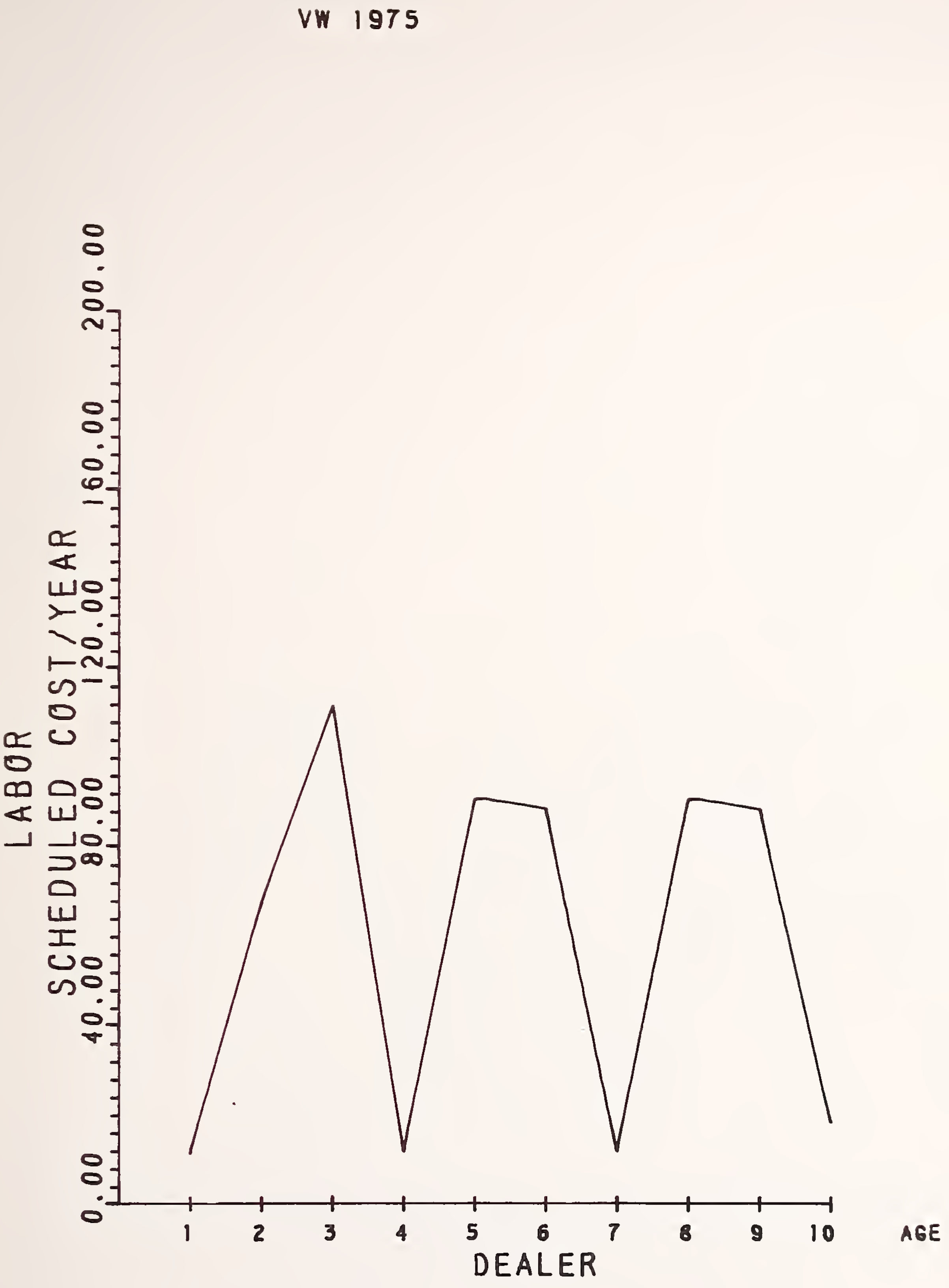

VW 1975
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-38

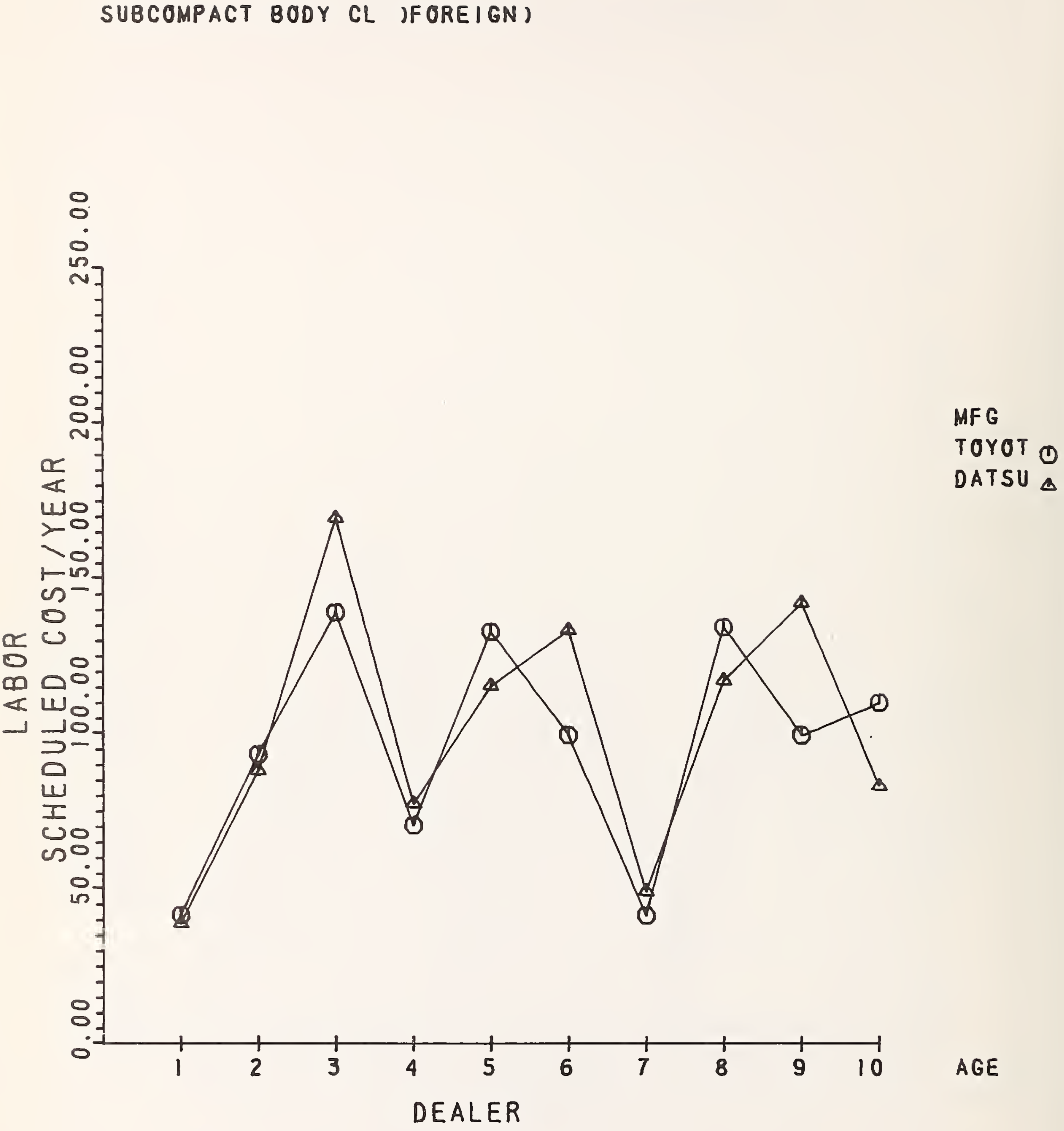

SUBCOMPACT BODY CL)FOREIGN)
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
TOYOT
DATSU

FIGURE A-39

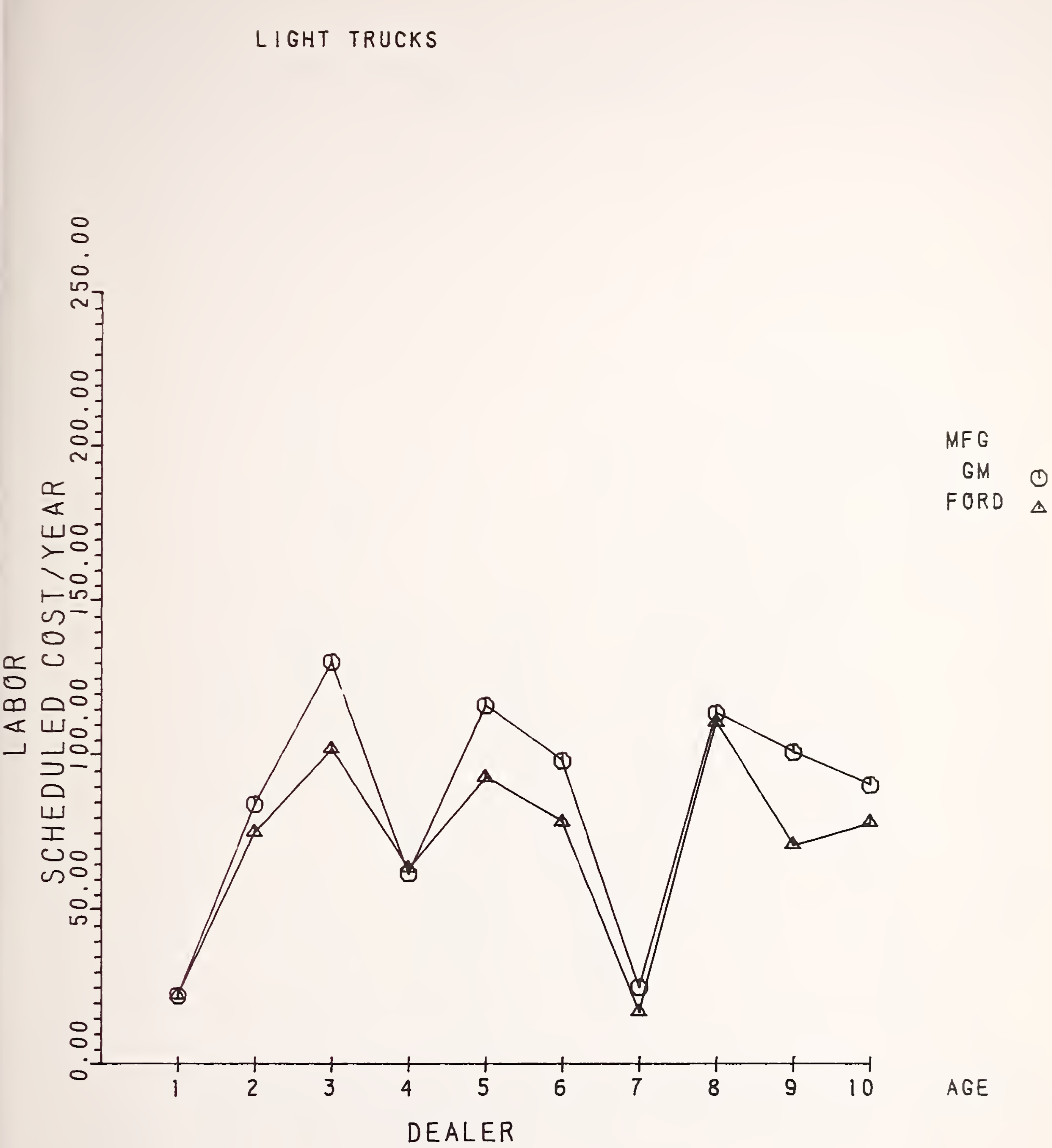

LIGHT TRUCKS
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM ○
FORD △

FIGURE A-40

VID BET 1 4 YEAR LT 7 LUXURY BODY CLASS

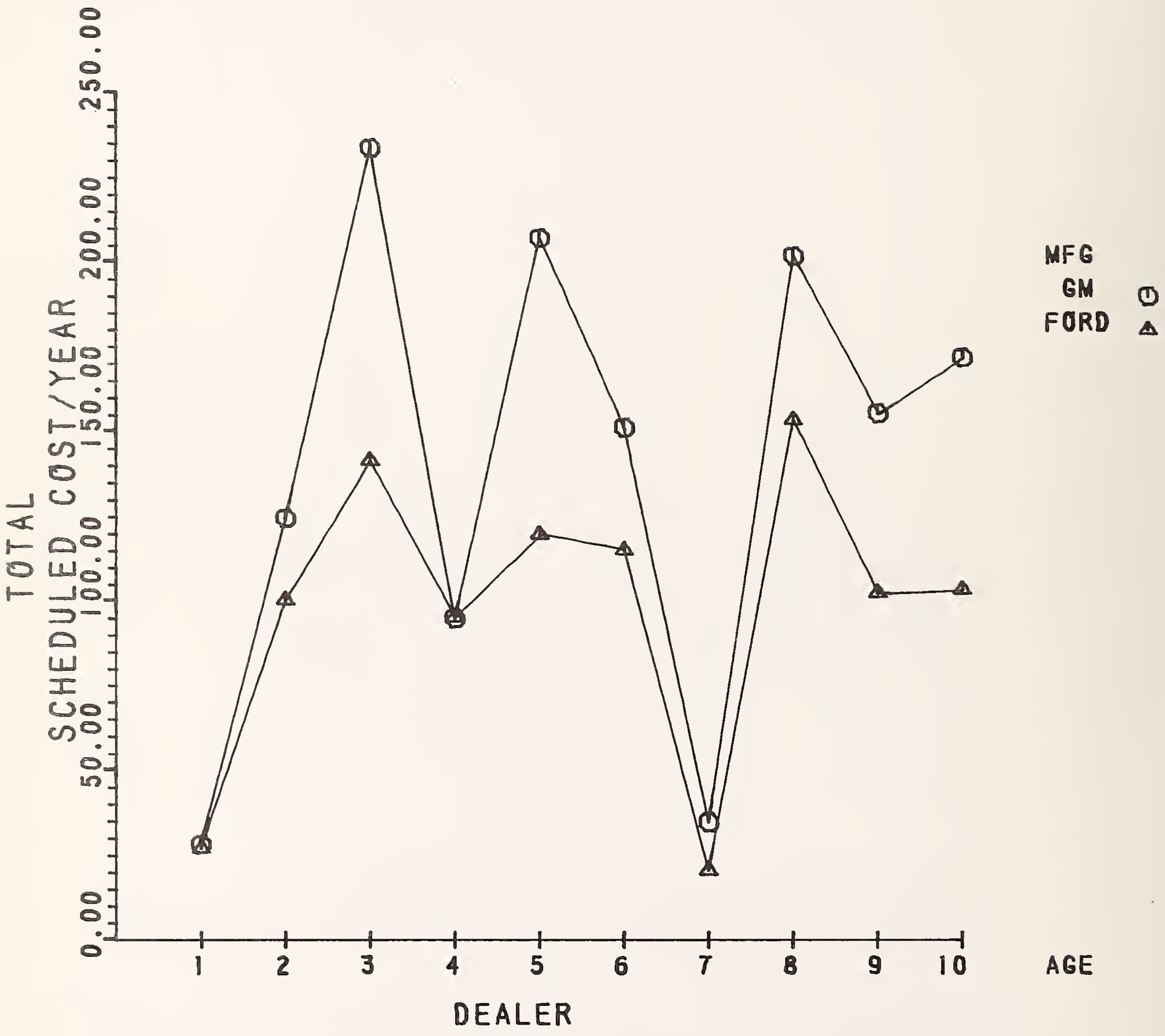


FIGURE A-41

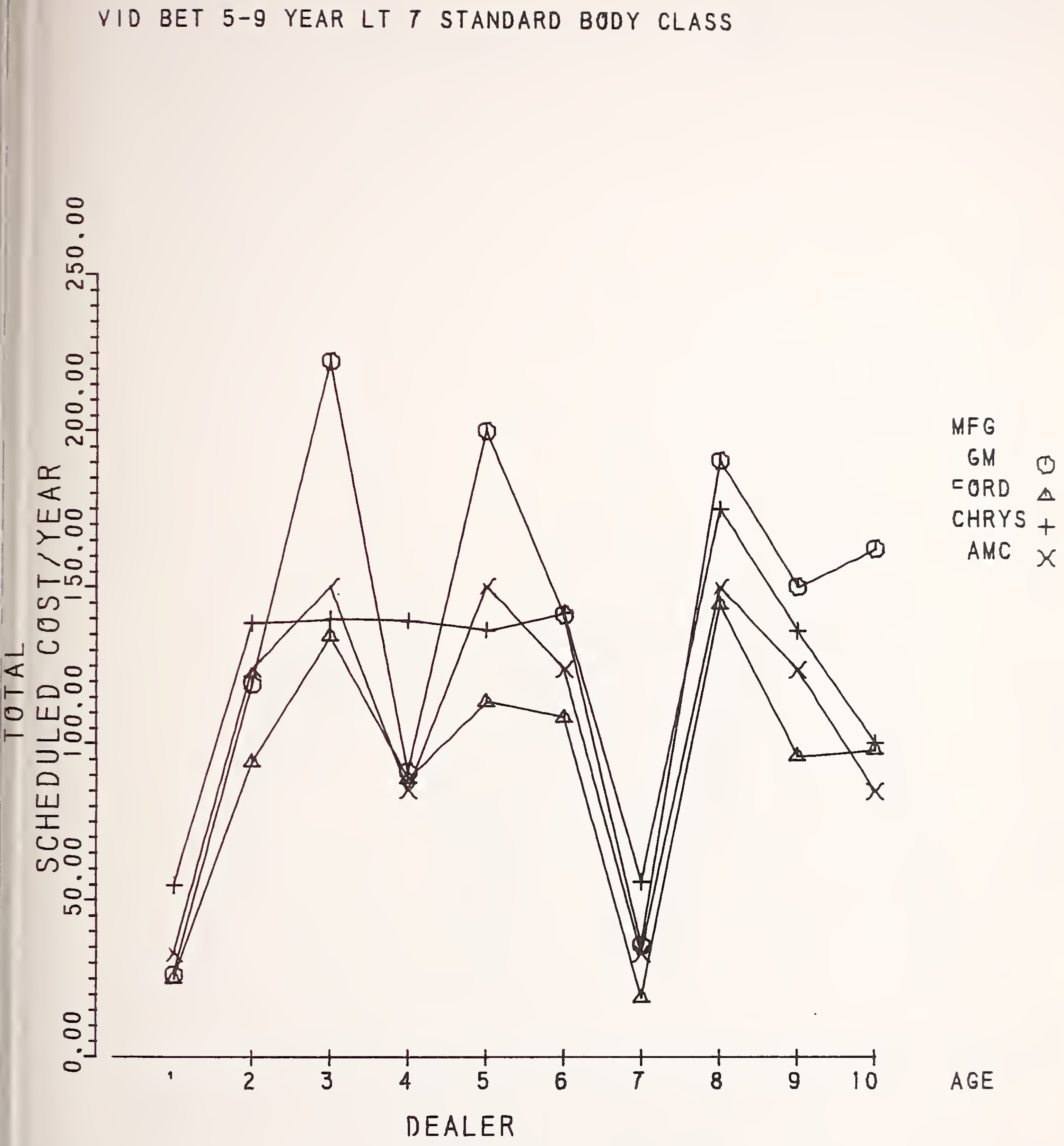

VID BET 5-9 YEAR LT 7 STANDARD BODY CLASS
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
AMC

FIGURE A-42

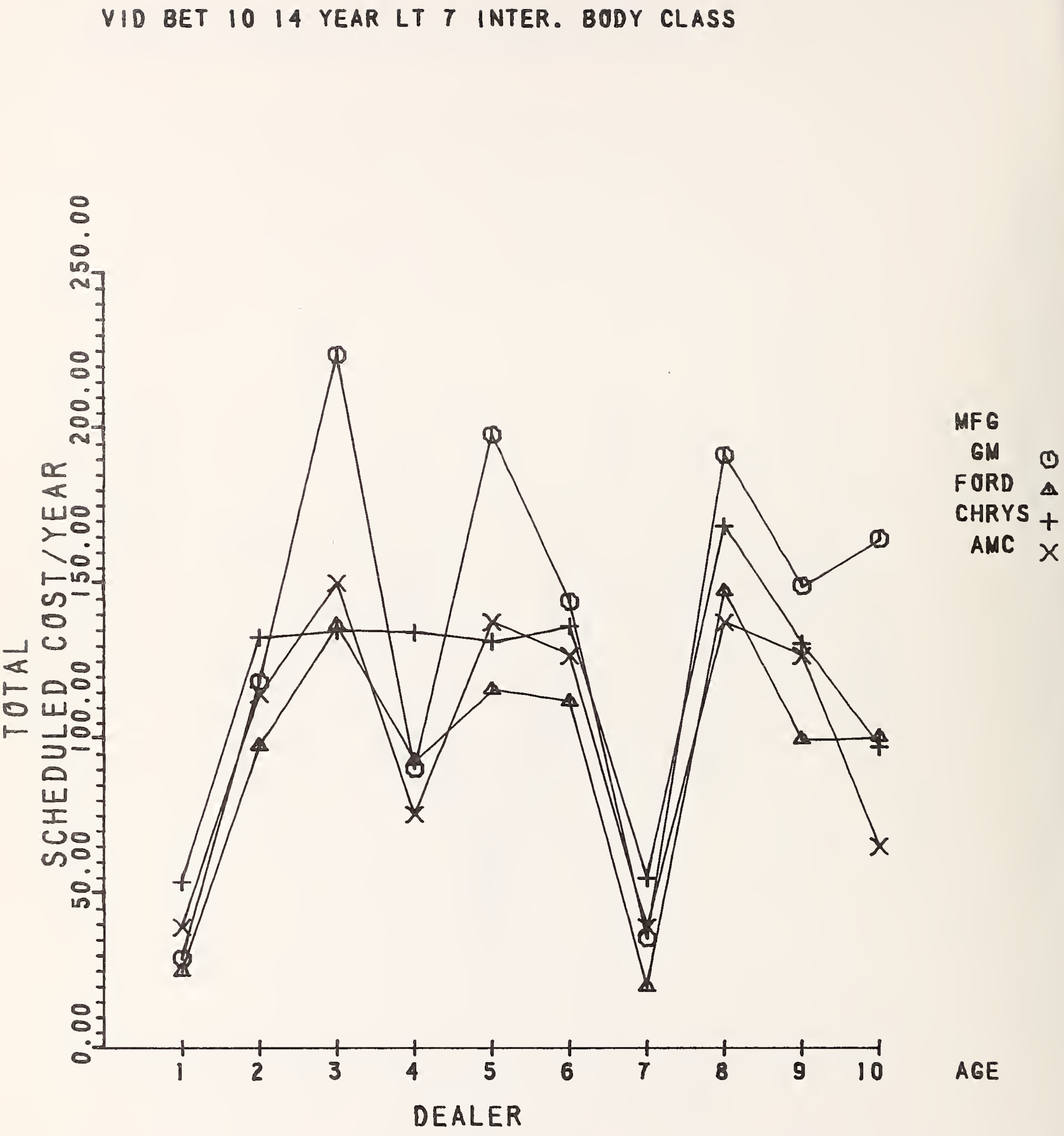

VID BET 10 14 YEAR LT 7 INTER. BODY CLASS
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM ⊖
FORD △
CHRYS +
AMC ×

Figure A-43

VID BET 15 22 YEAR LT 7 COMPACT BODY CLASS

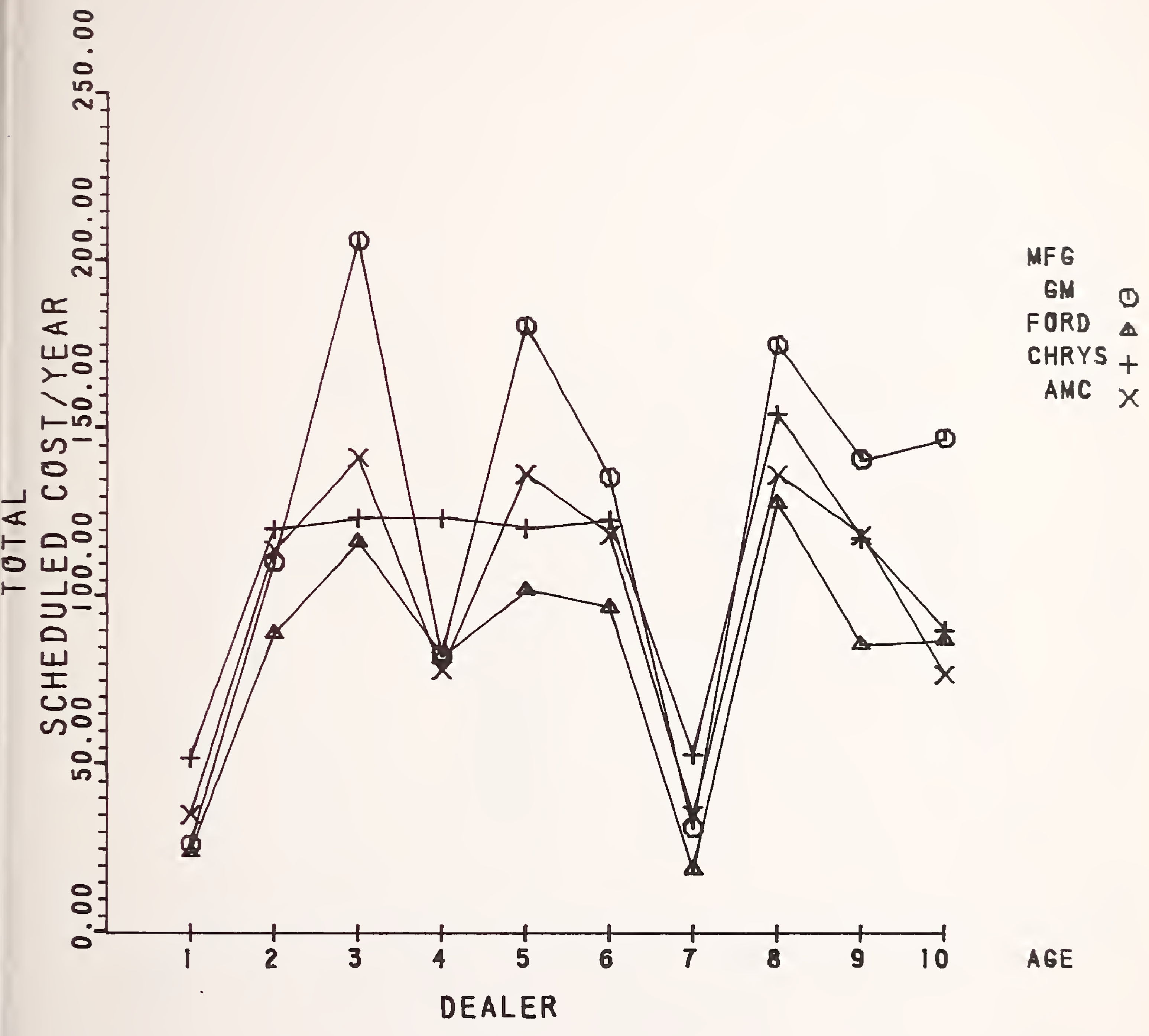


FIGURE A-44

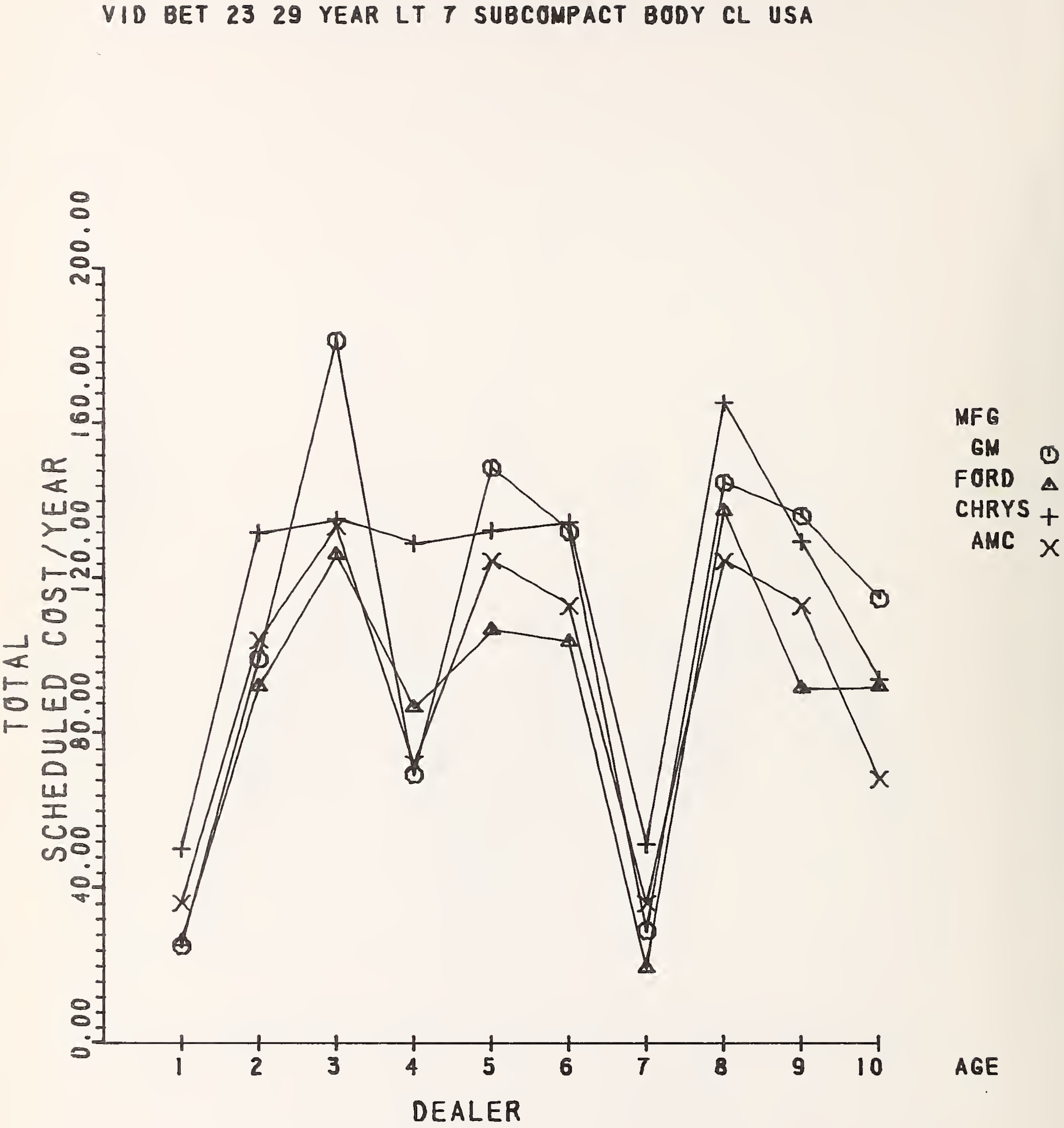

VID BET 23 29 YEAR LT 7 SUBCOMPACT BODY CL USA
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-45

VW 1975

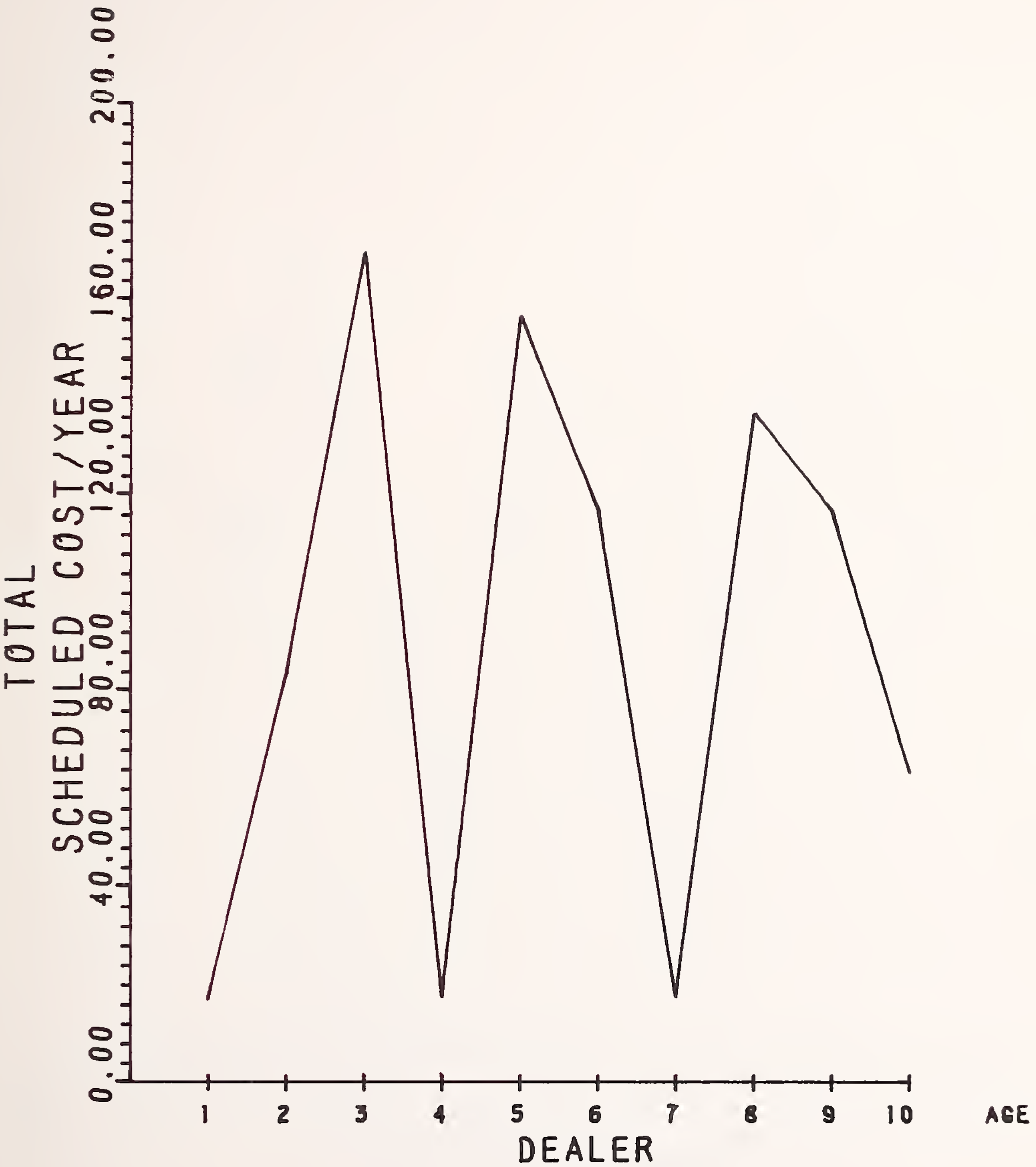


FIGURE A-46

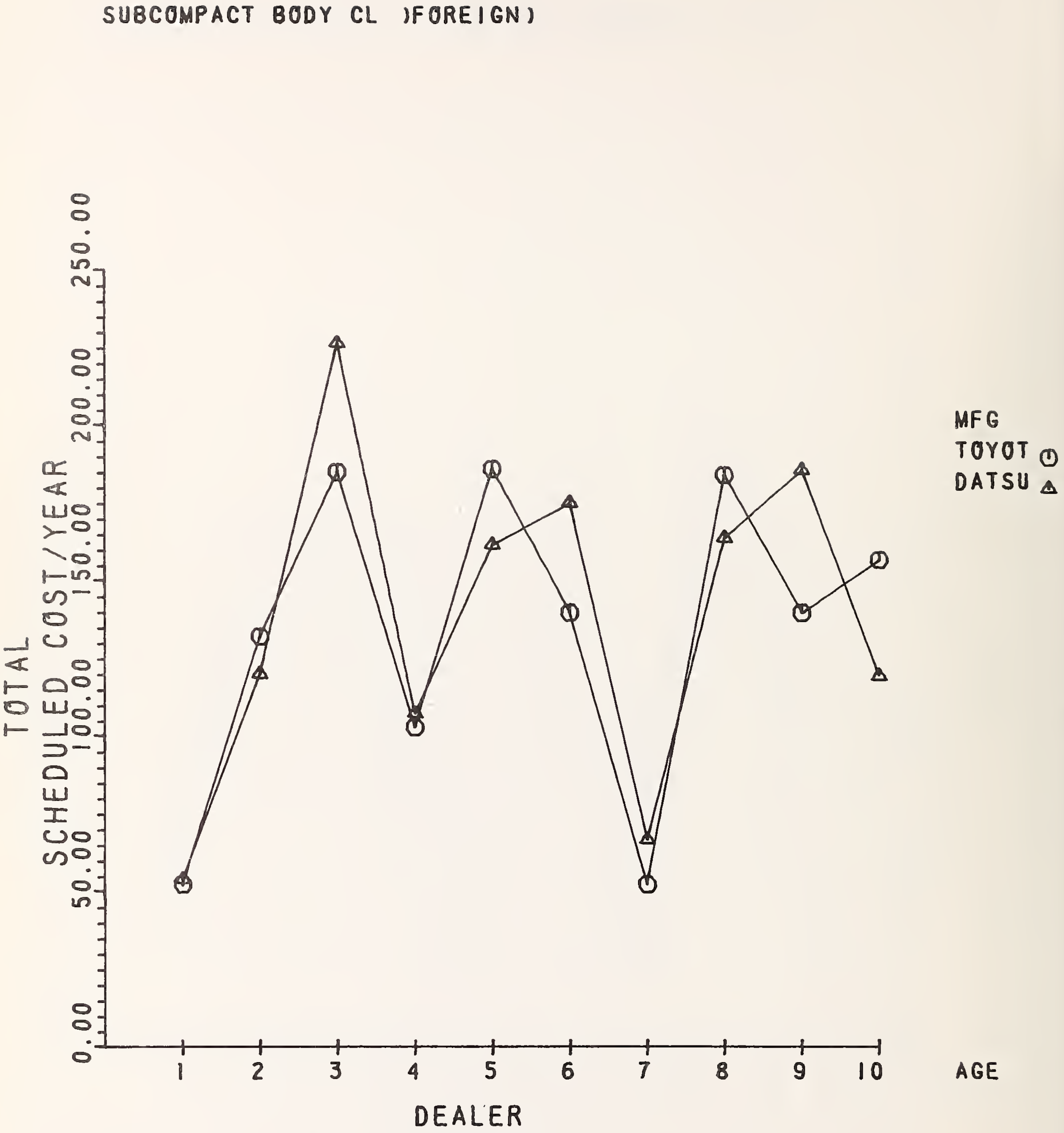

SUBCOMPACT BODY CL)FOREIGN)
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
TOYOT ○
DATSU △

FIGURE A-47

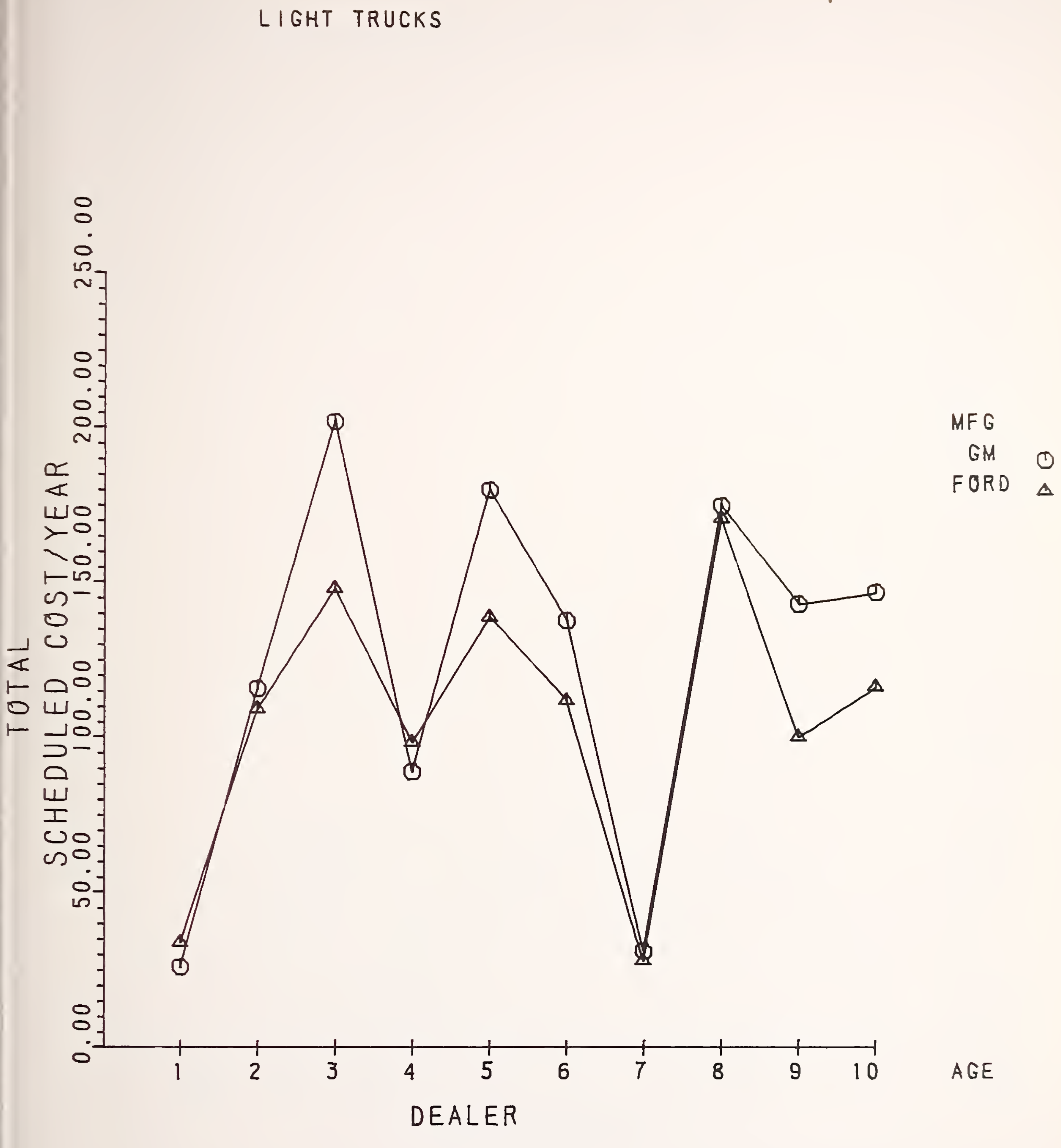

LIGHT TRUCKS
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △

FIGURE A-48

WT CLASS OVER 4000 LB

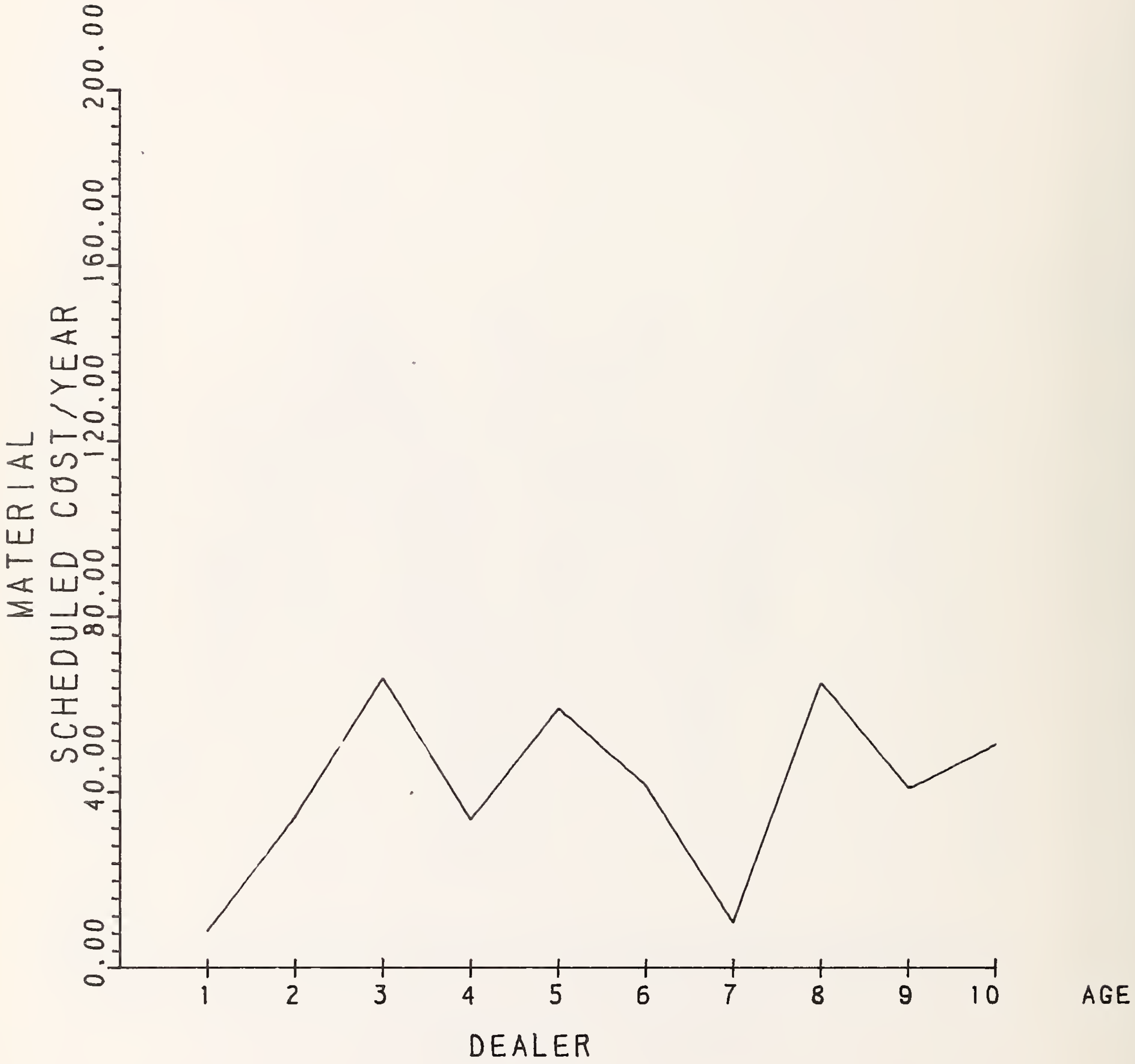


FIGURE A-49

WT CLASS 3601-4000 LB

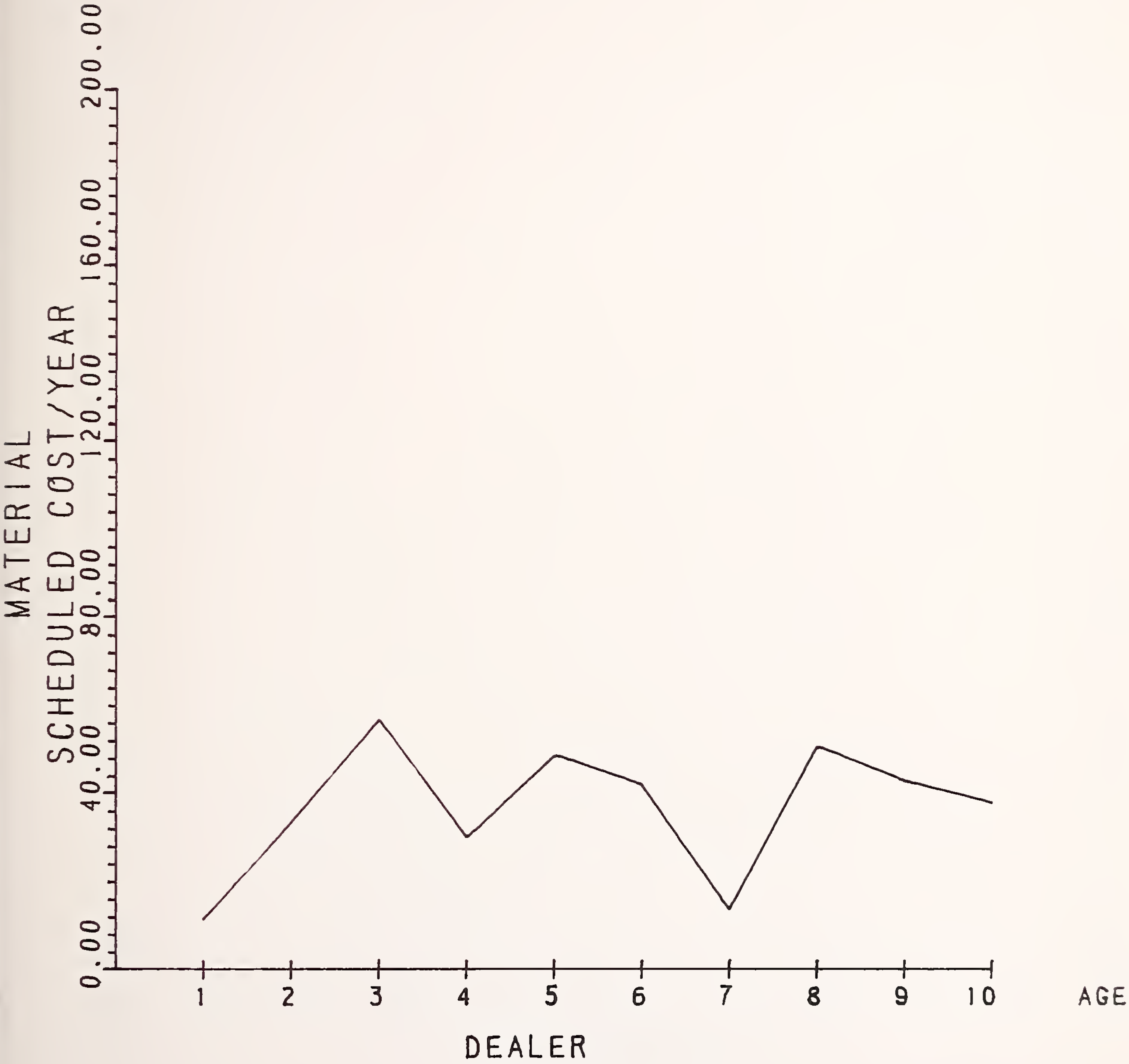


FIGURE A-50

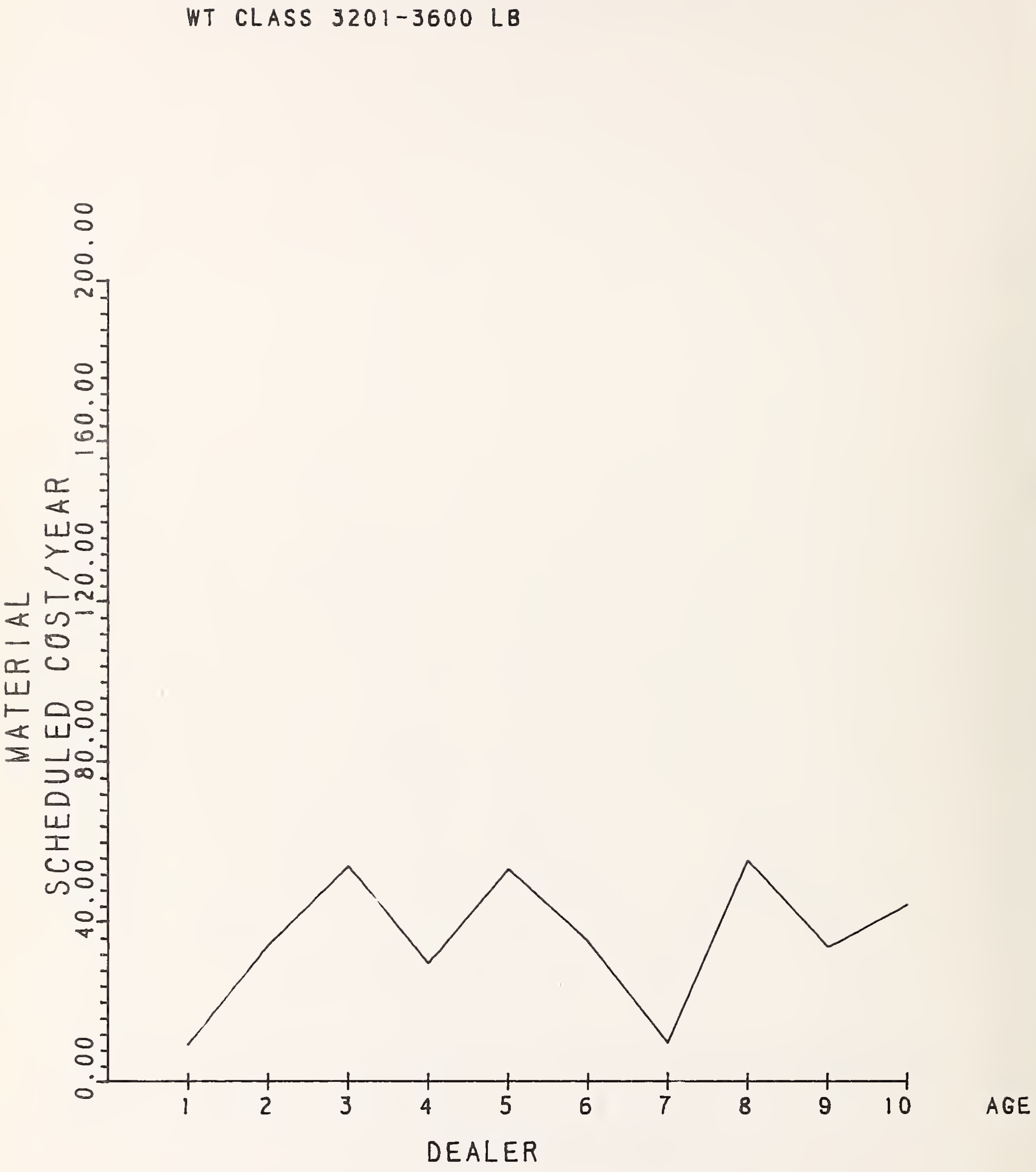

WT CLASS 3201-3600 LB
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-51

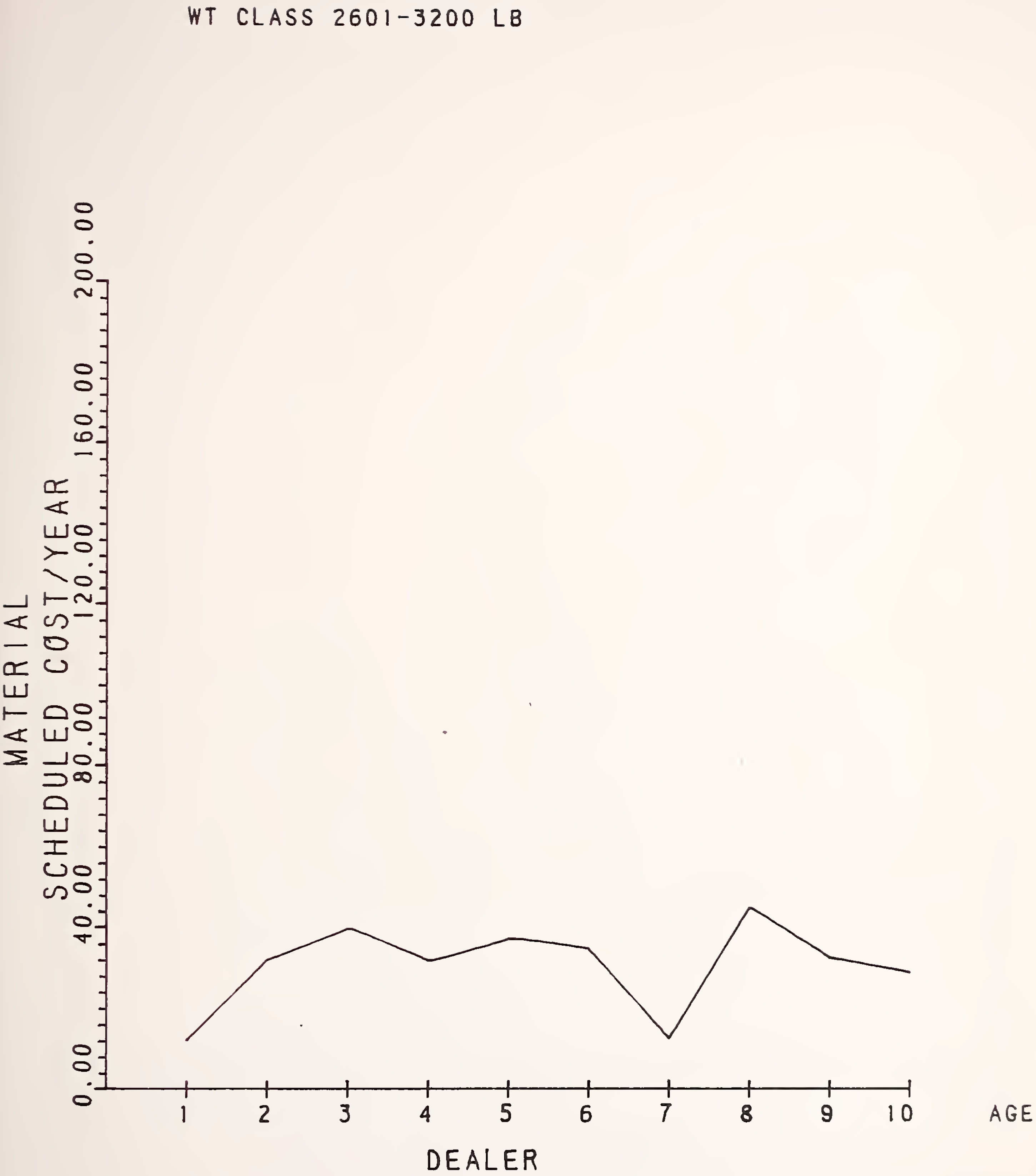

WT CLASS 2601-3200 LB
MATERIAL
SCHEDULED CØST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-52

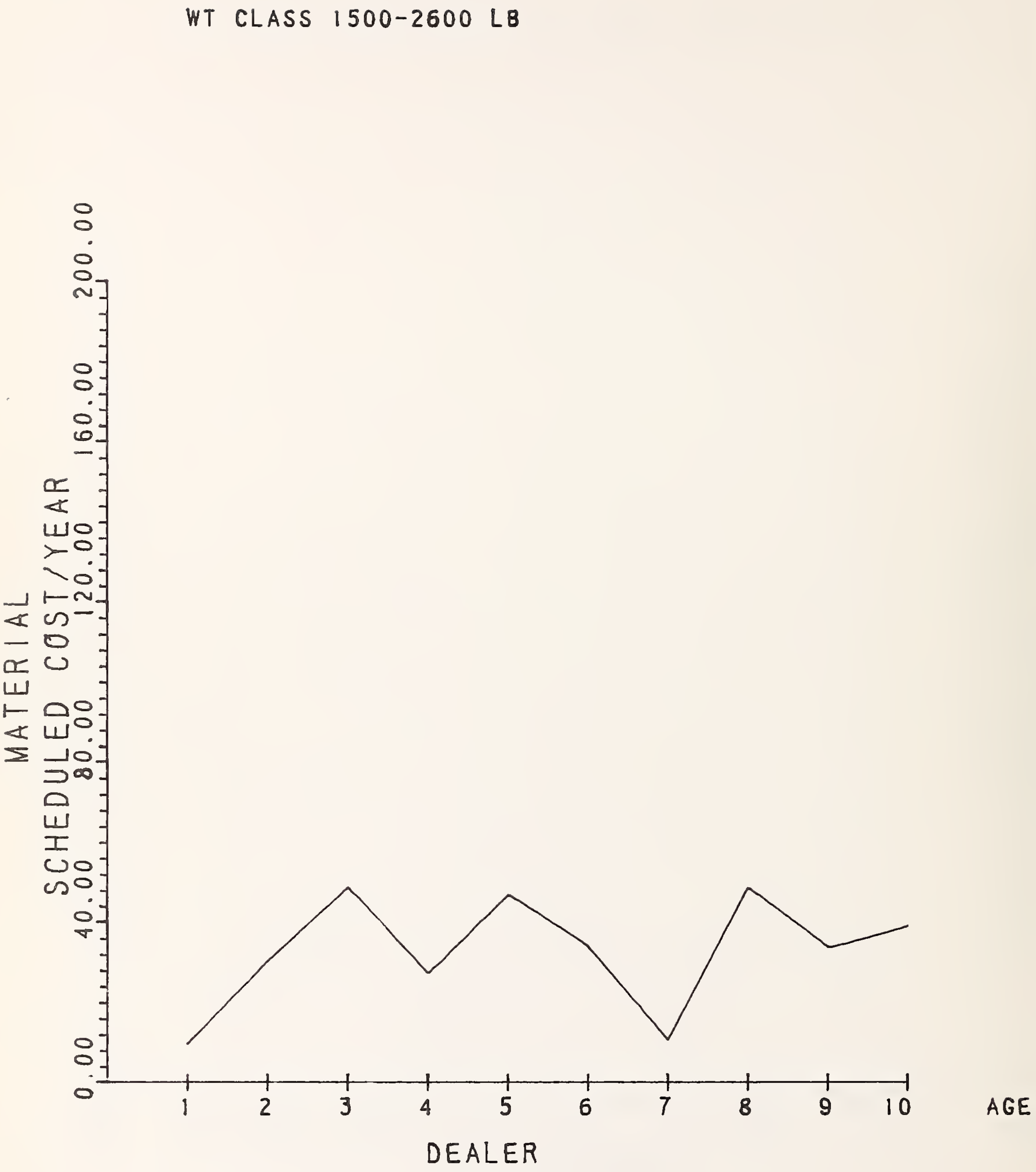

WT CLASS 1500-2600 LB
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-53

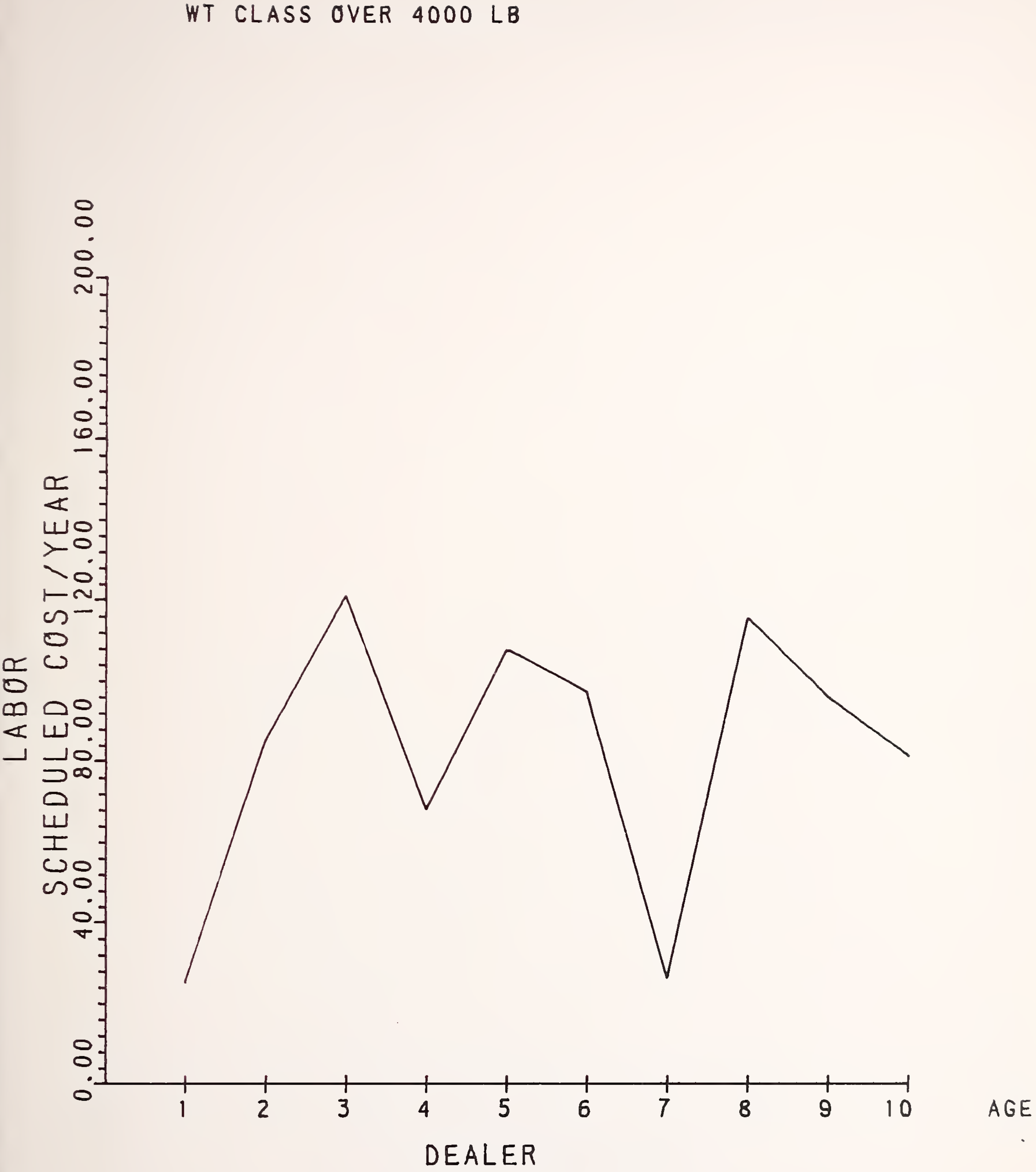

WT CLASS OVER 4000 LB
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-54

WT CLASS 3601-4000 LB

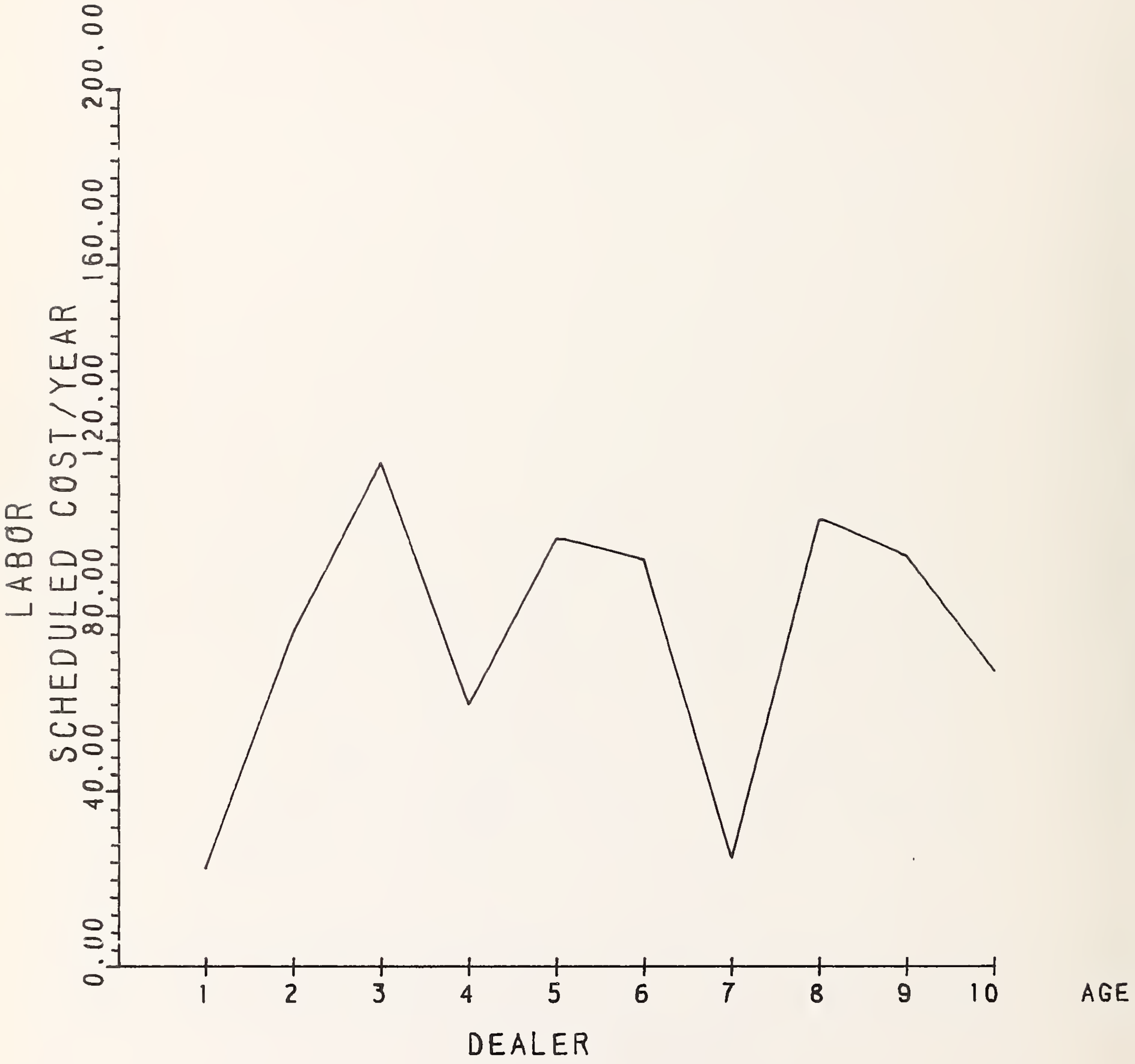


FIGURE A-55

WT CLASS 3201-3600 LB

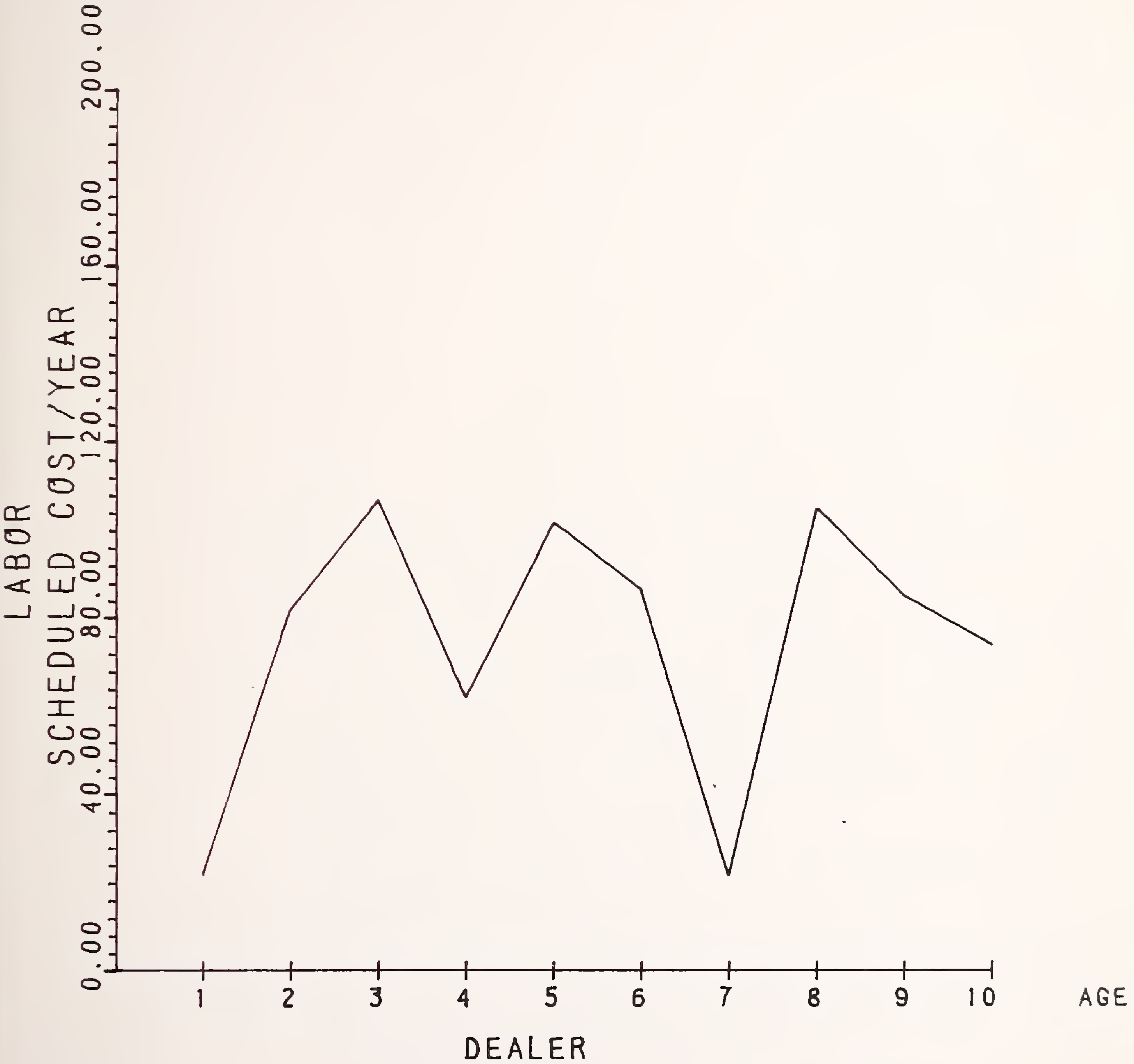


FIGURE A-56

WT CLASS 2601-3200 LB

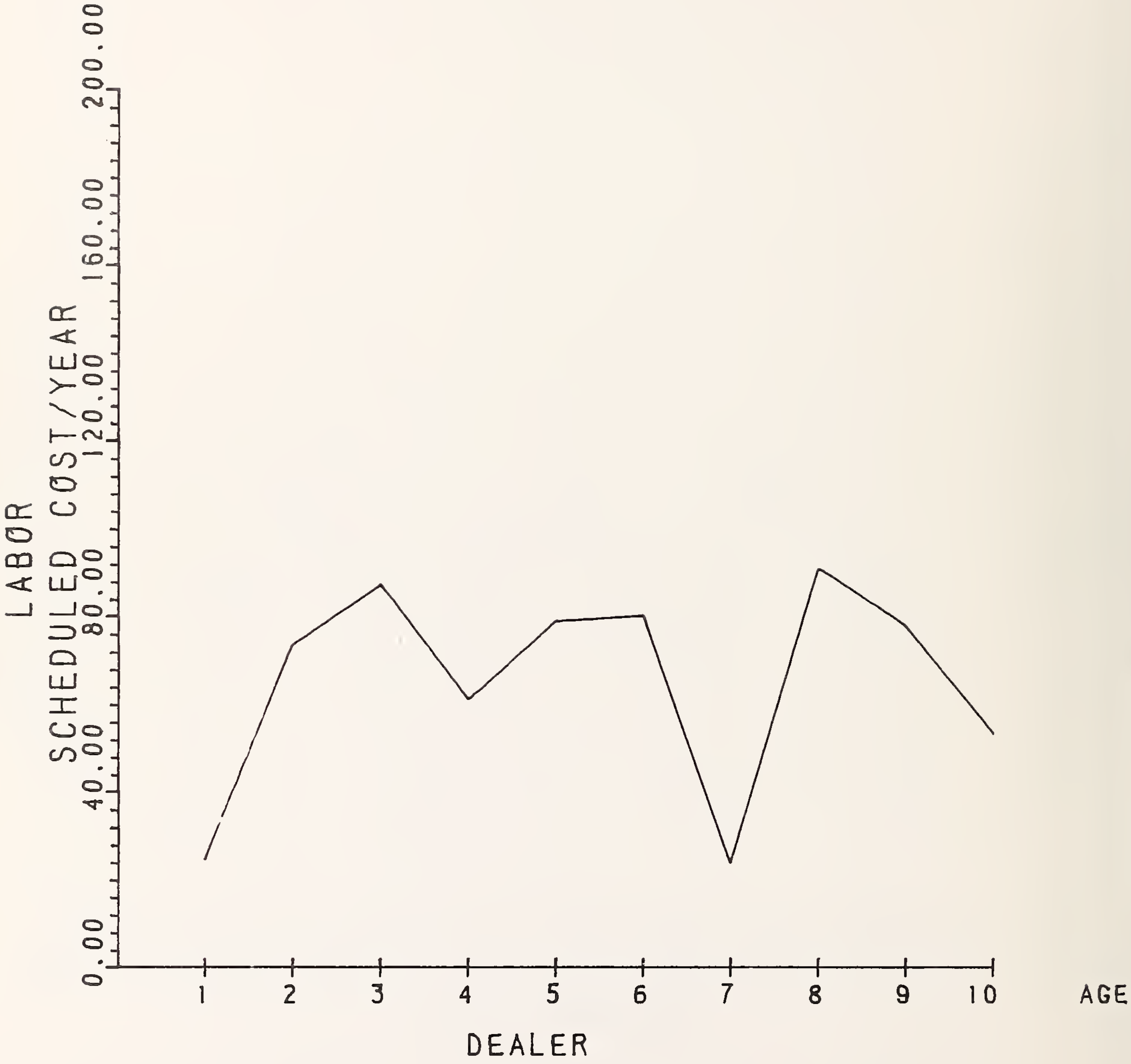


FIGURE A-57

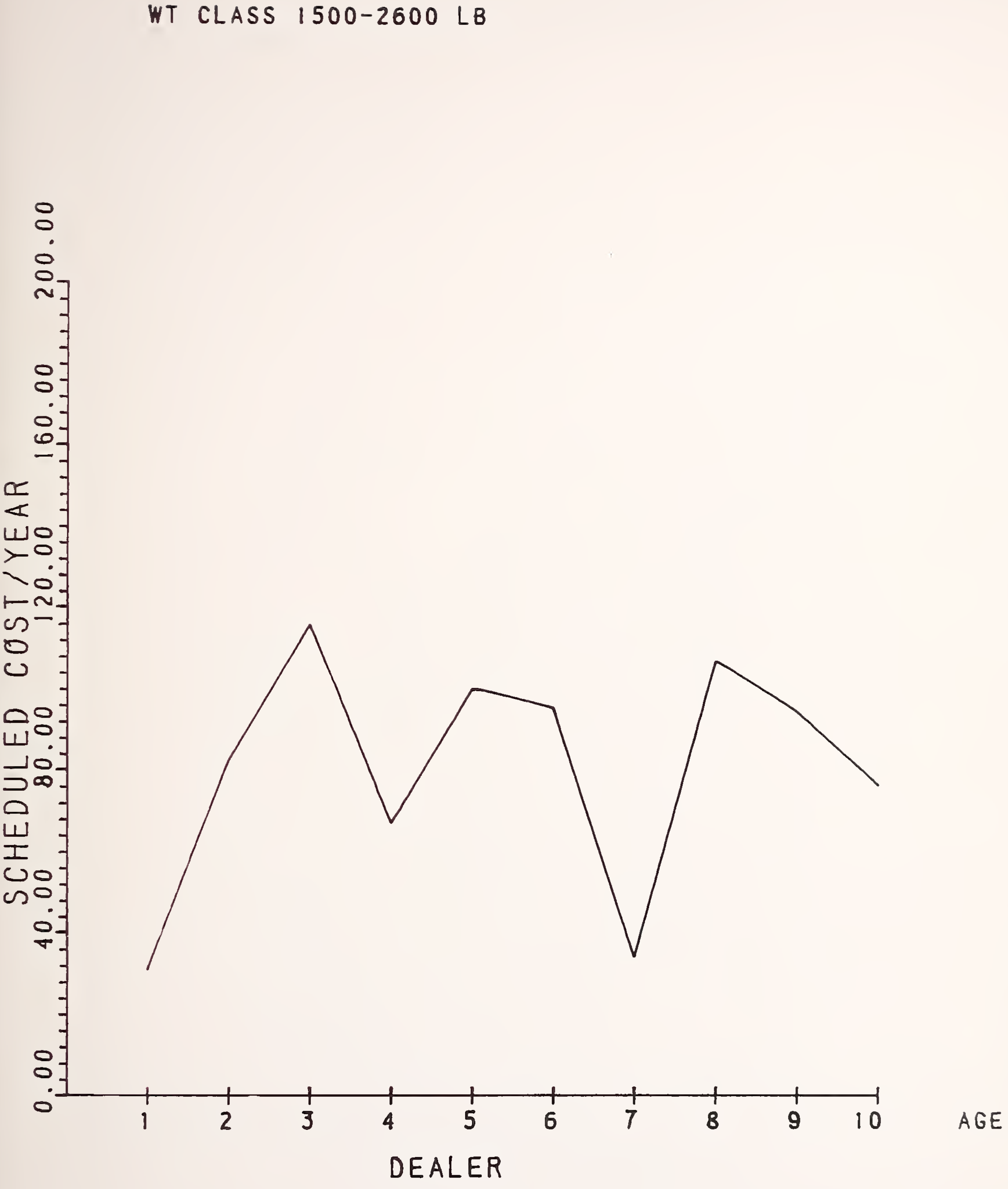

WT CLASS 1500-2600 LB
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-58

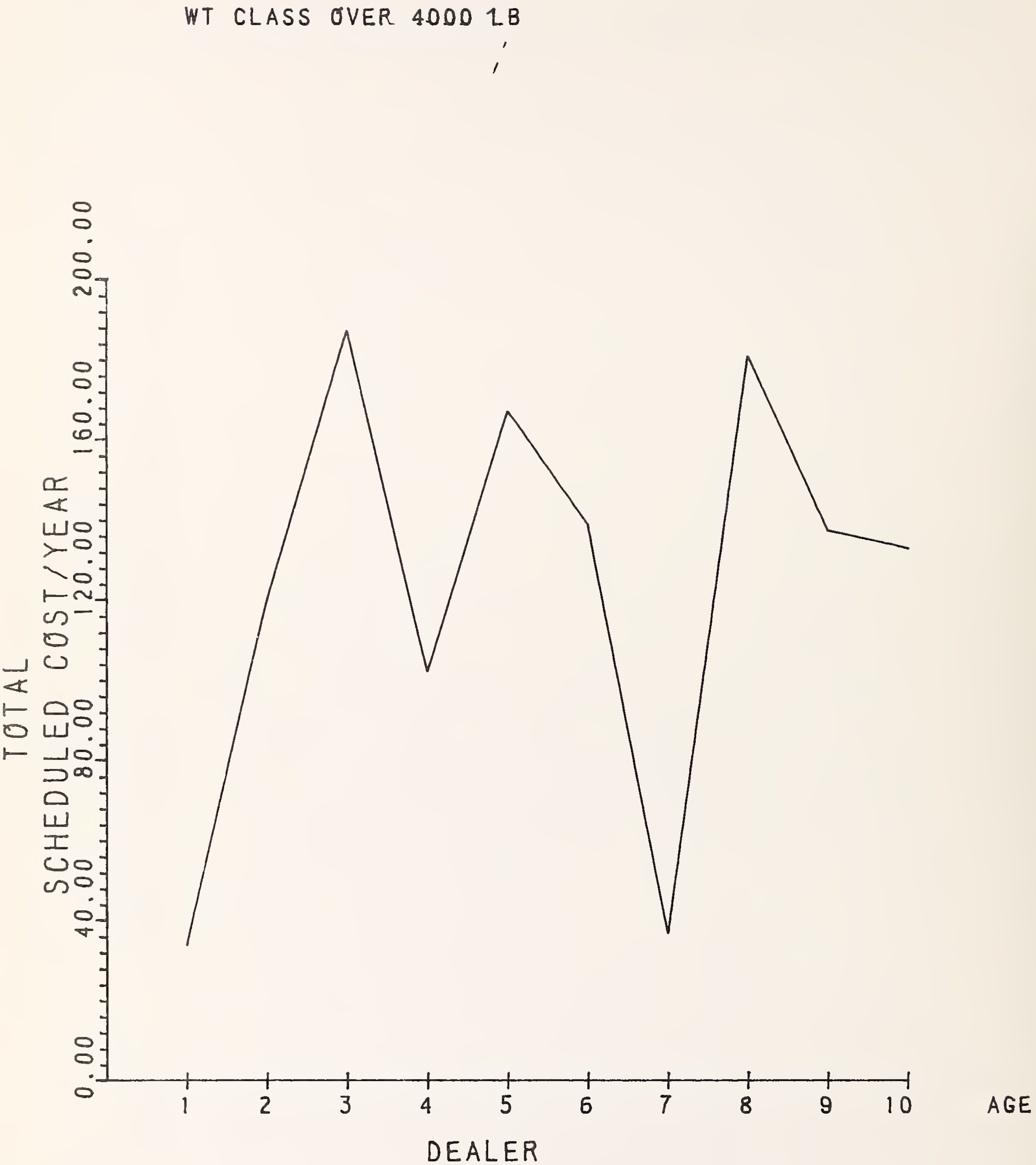

WT CLASS OVER 4000 LB
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-59

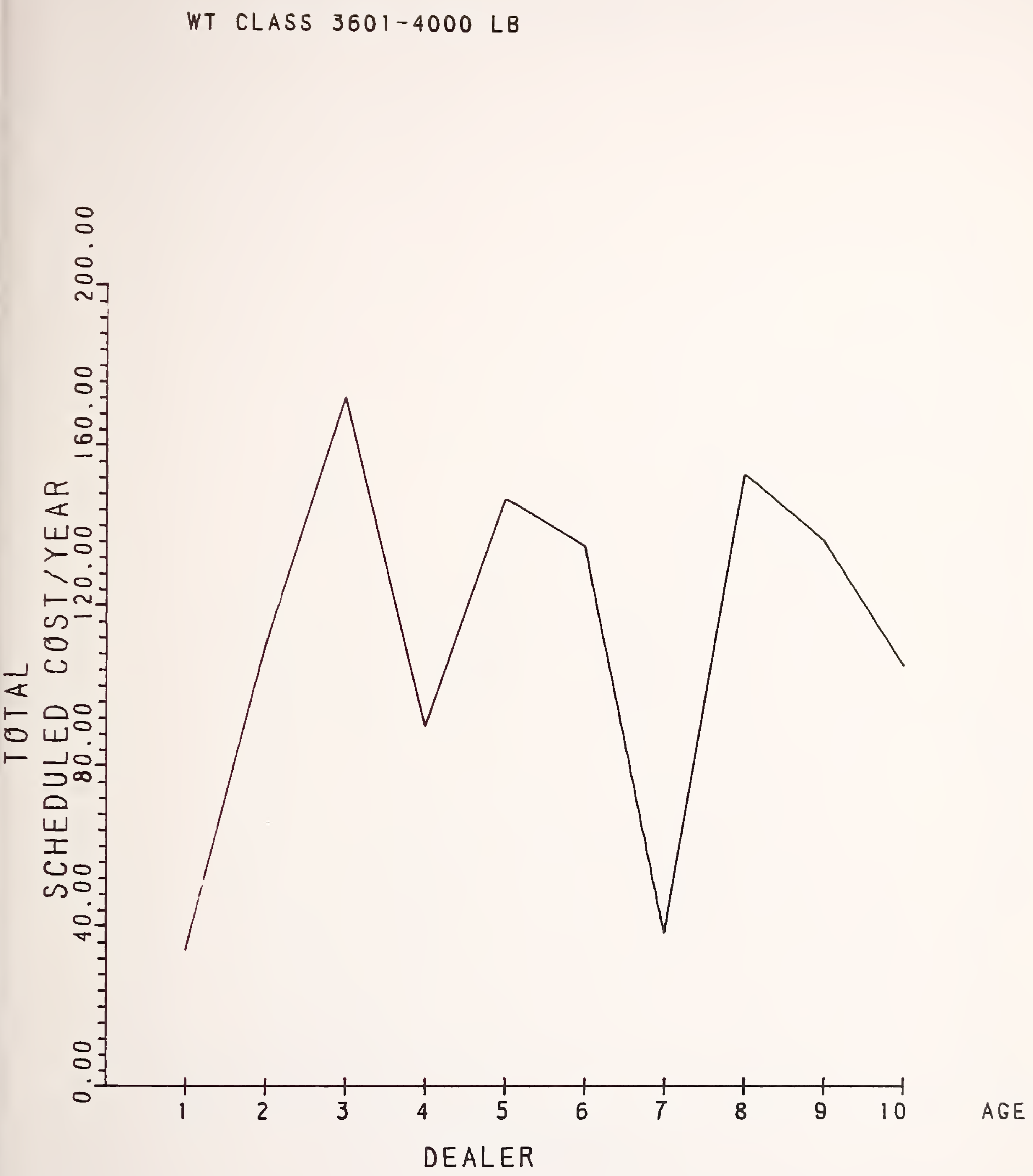

WT CLASS 3601-4000 LB
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-60

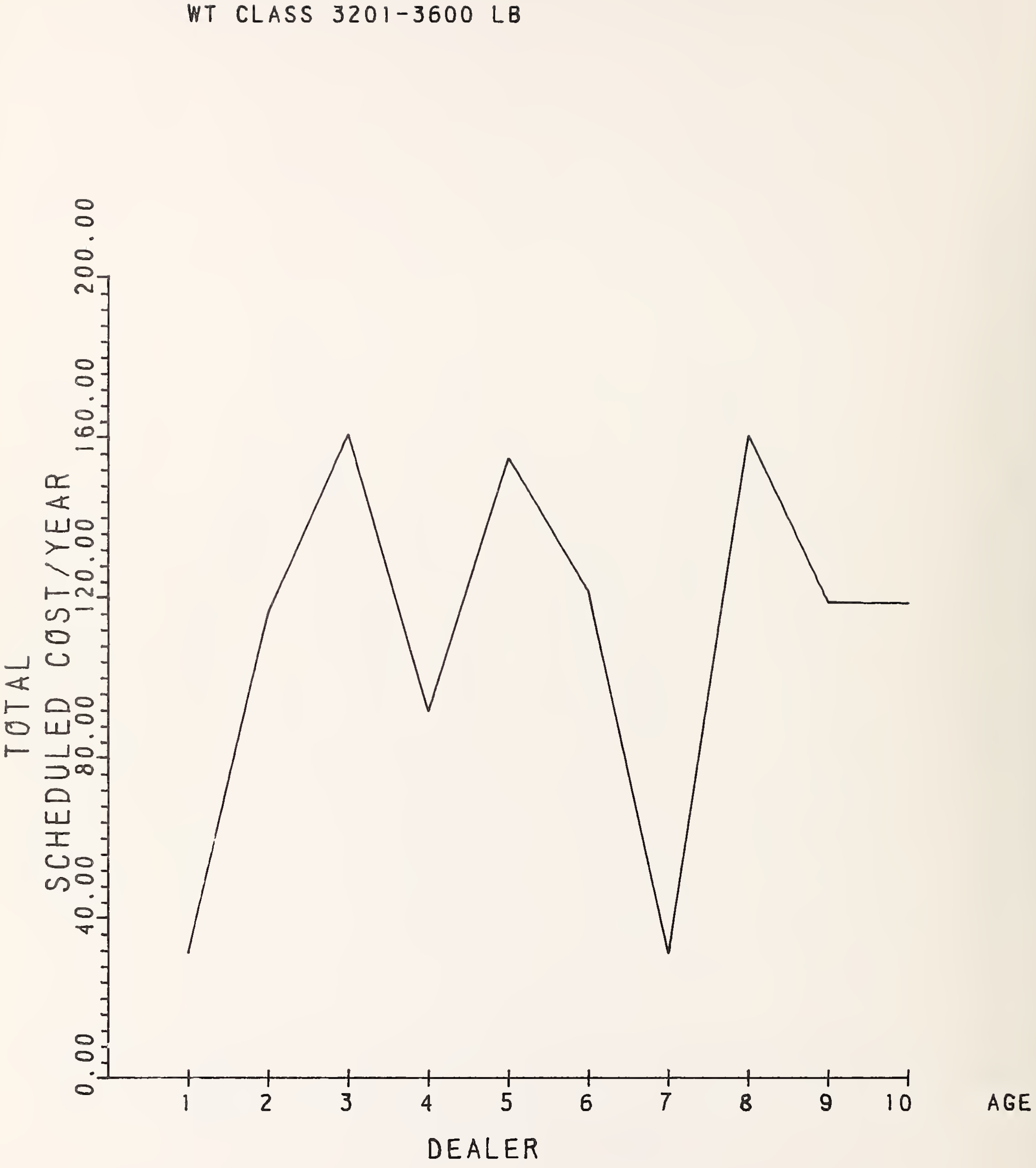

WT CLASS 3201-3600 LB
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-61

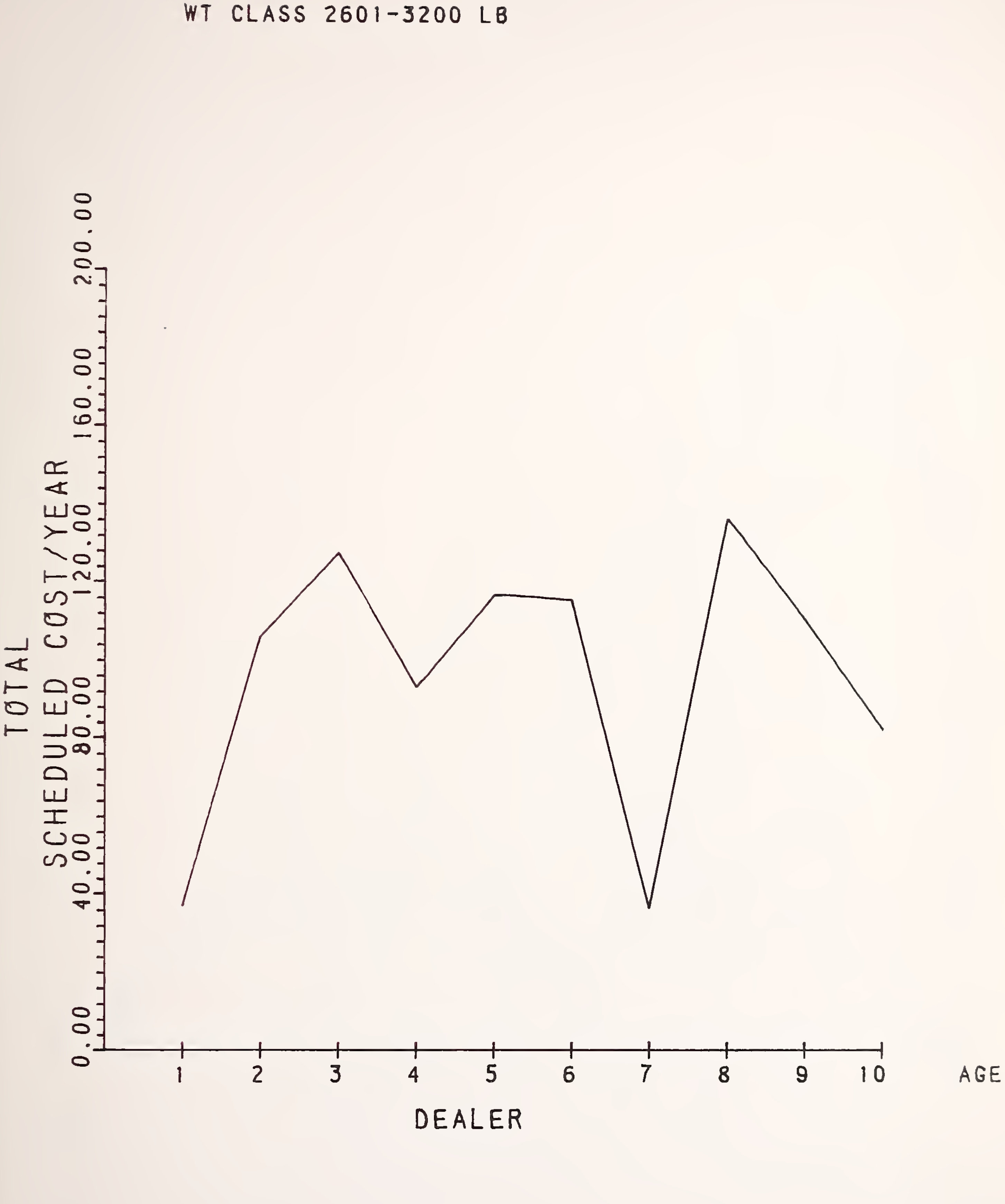

WT CLASS 2601-3200 LB
TØTAL
SCHEDULED CØST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-62

WT CLASS 1500-2600 LB

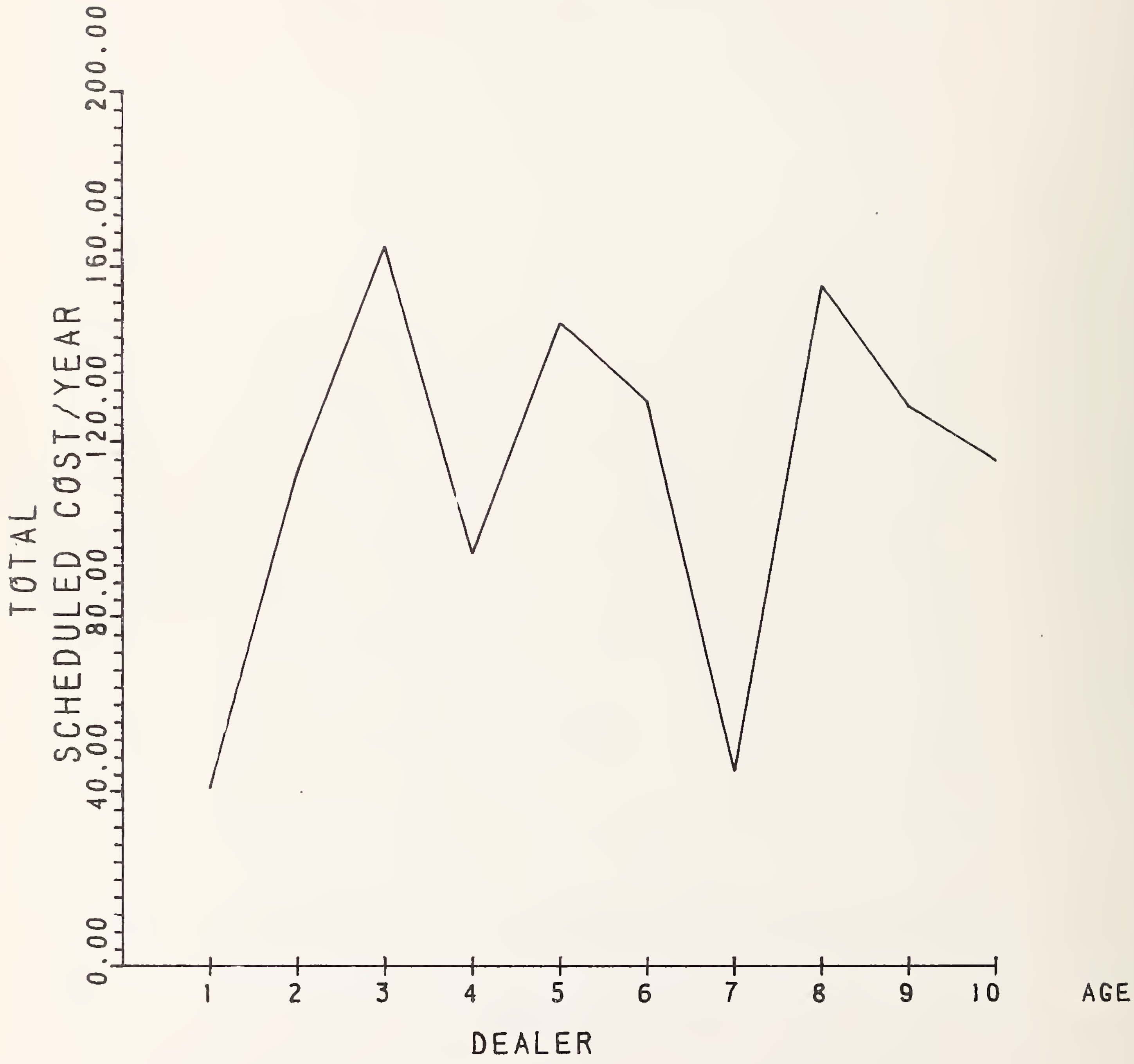


FIGURE A-63

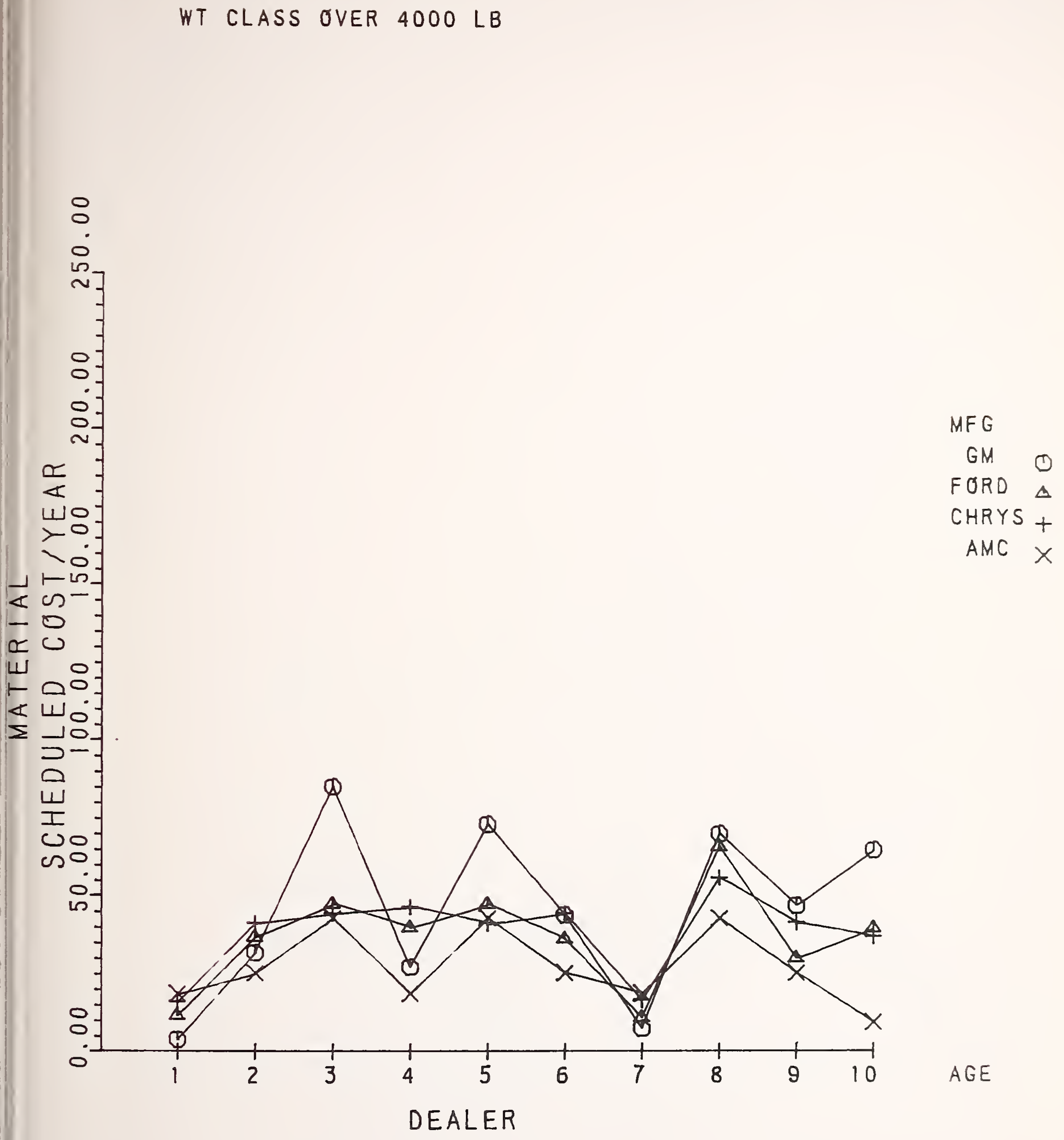

WT CLASS OVER 4000 LB
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-64

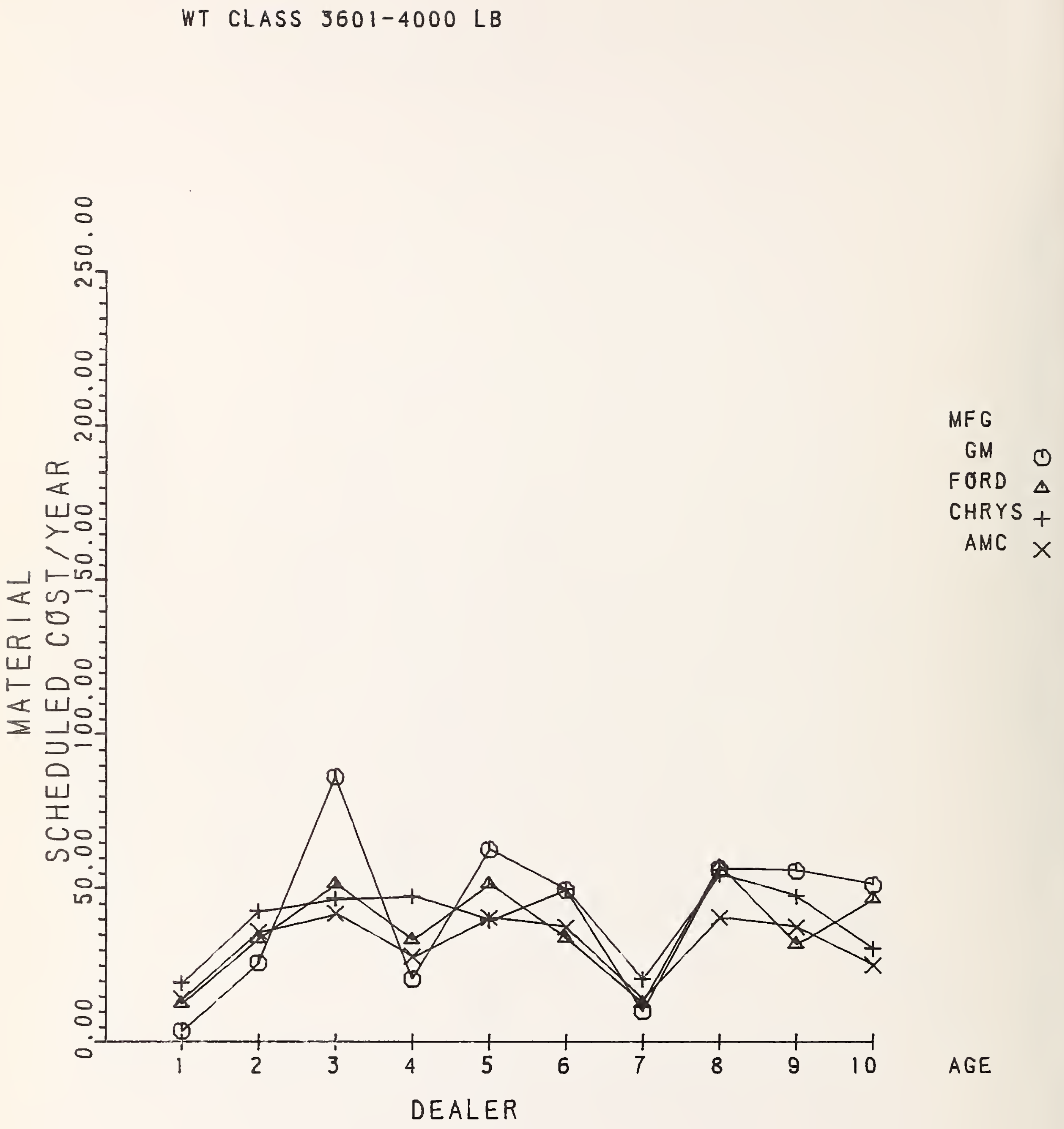

WT CLASS 3601-4000 LB
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
AMC

FIGURE A-65

WT CLASS 3201-3600 LB

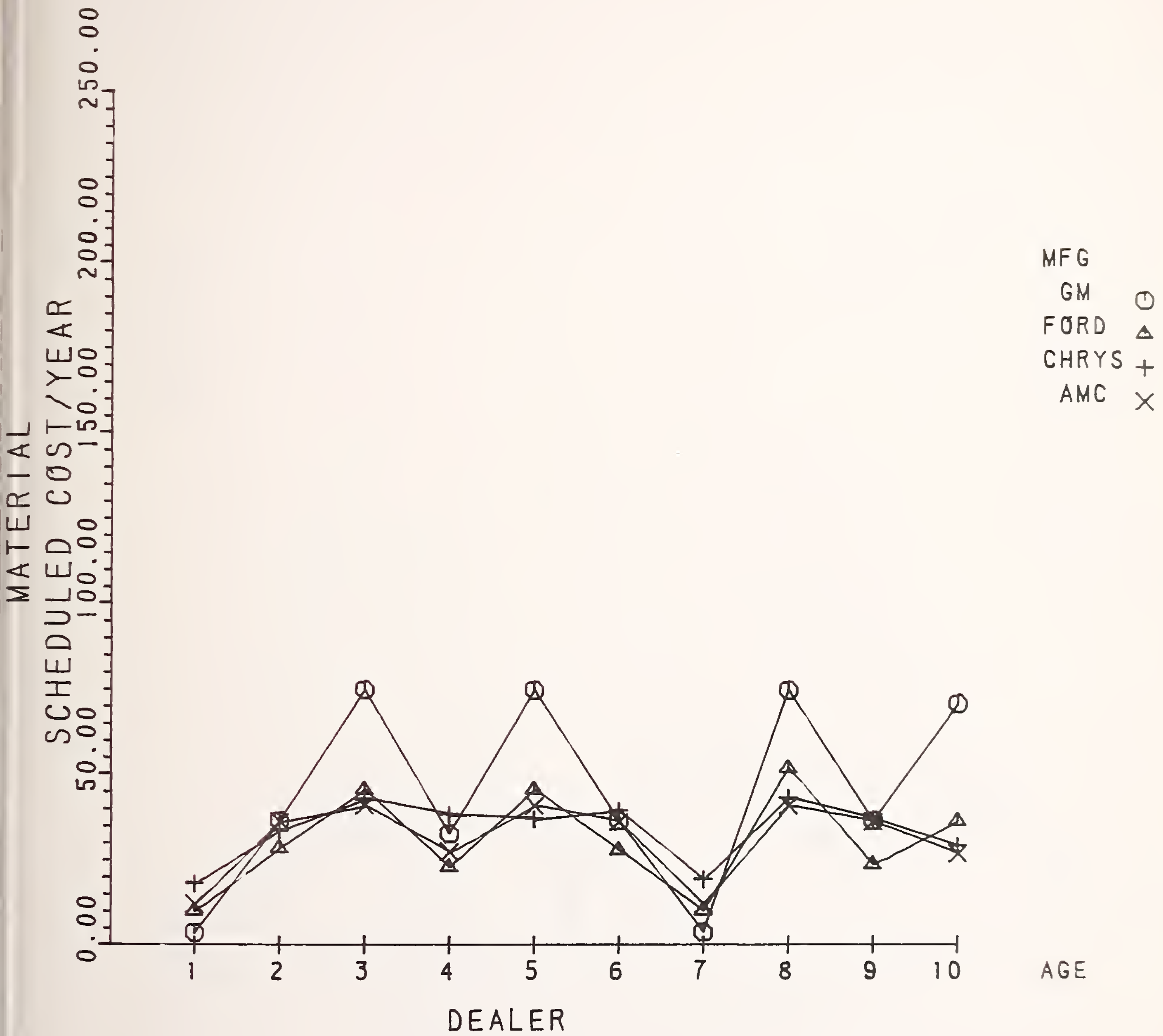


FIGURE A-66

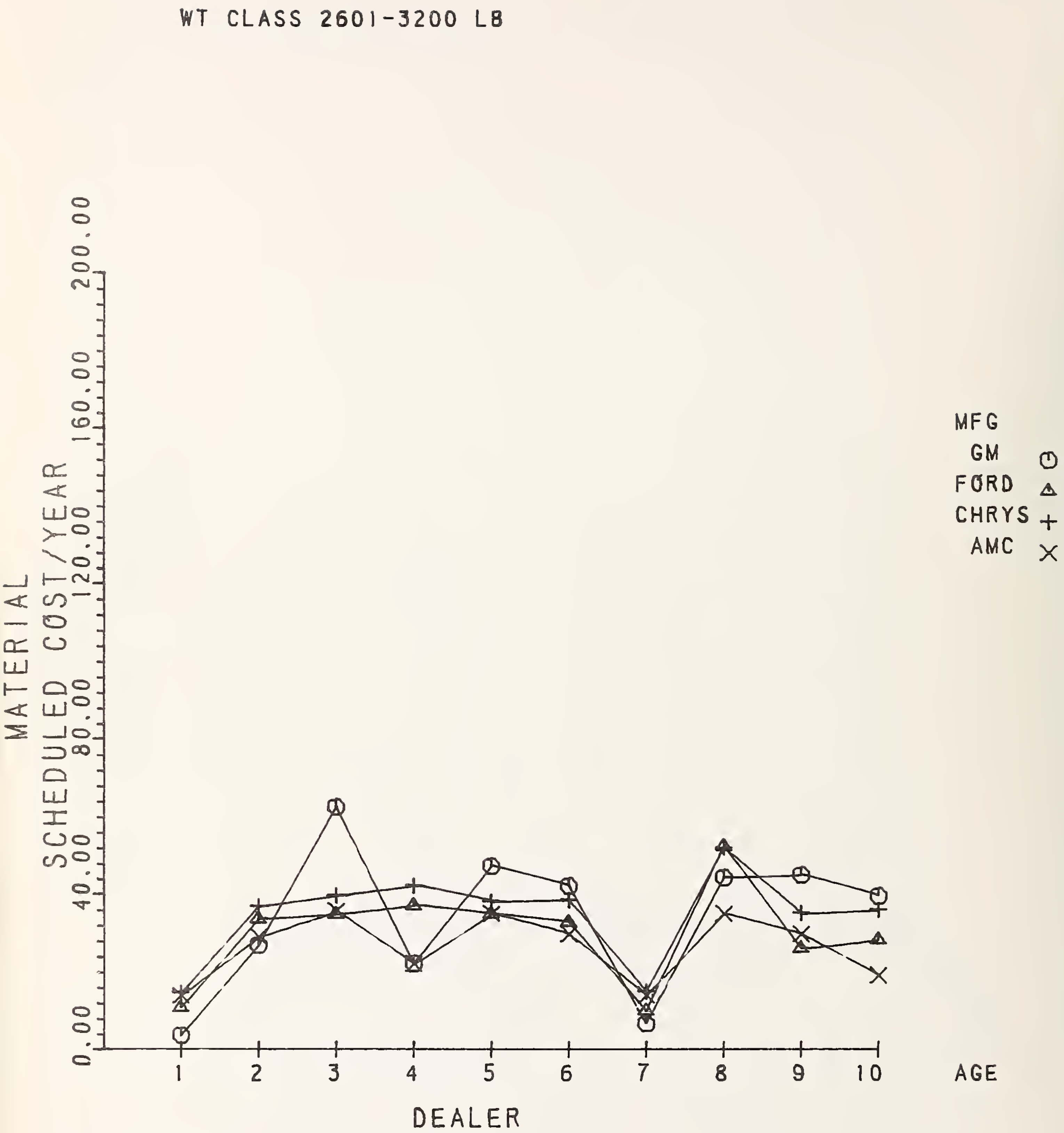

WT CLASS 2601-3200 LB
MATERIAL
SCHEDULED CØST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FØRD
CHRYS
AMC

FIGURE A-67

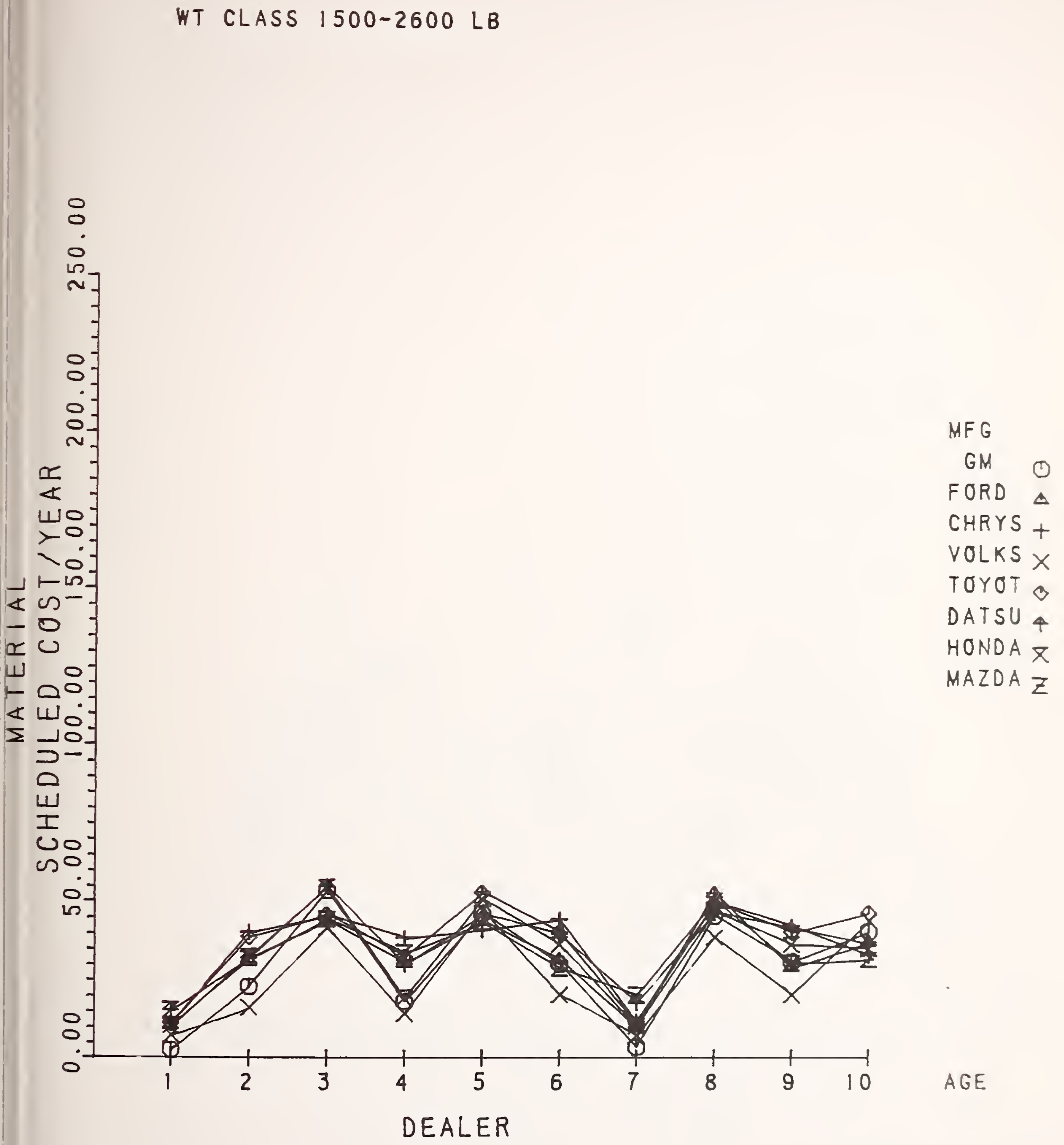

WT CLASS 1500-2600 LB
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
VOLKS
TOYOT
DATSU
HONDA
MAZDA

FIGURE A-68

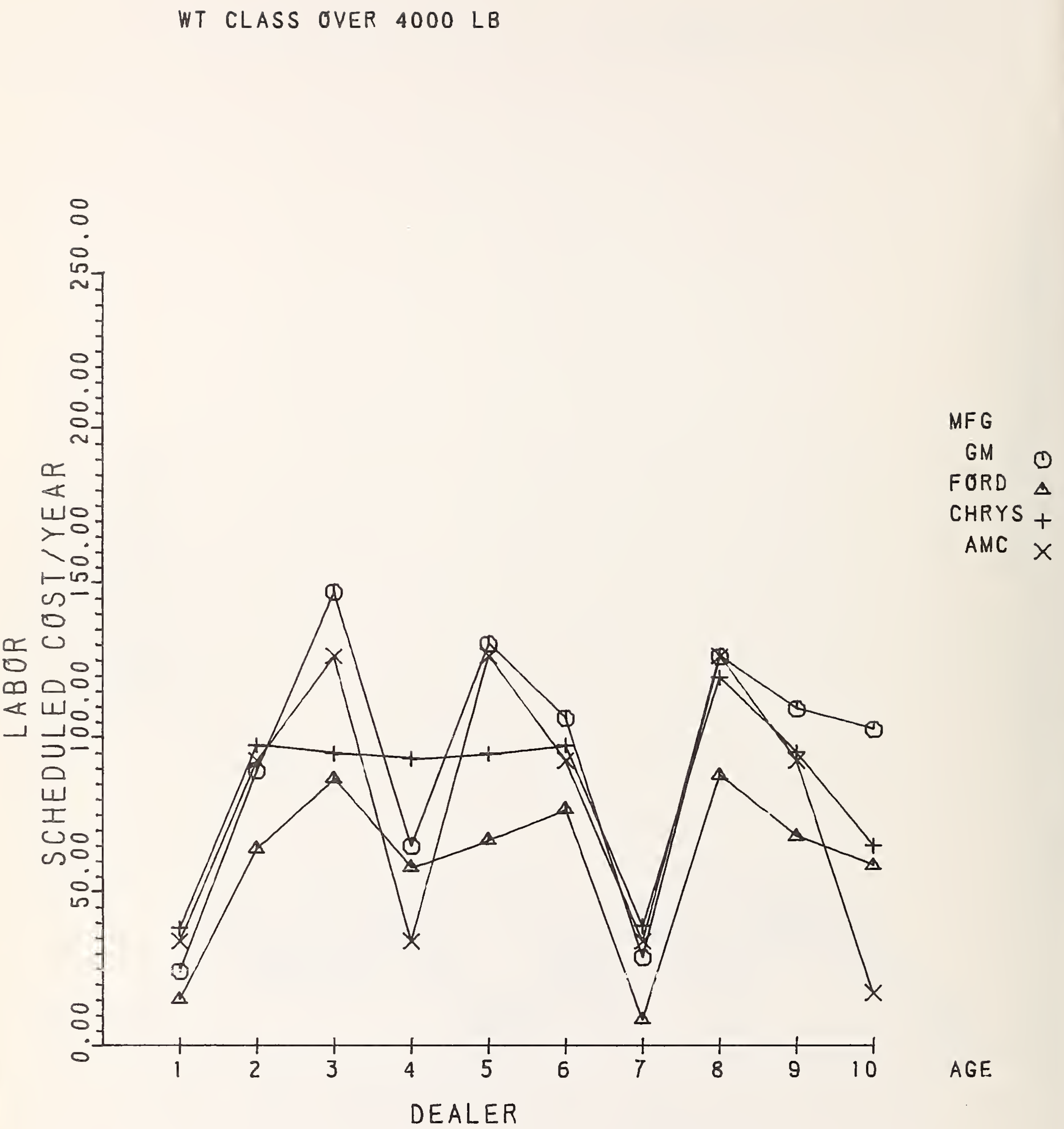

WT CLASS OVER 4000 LB
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-69

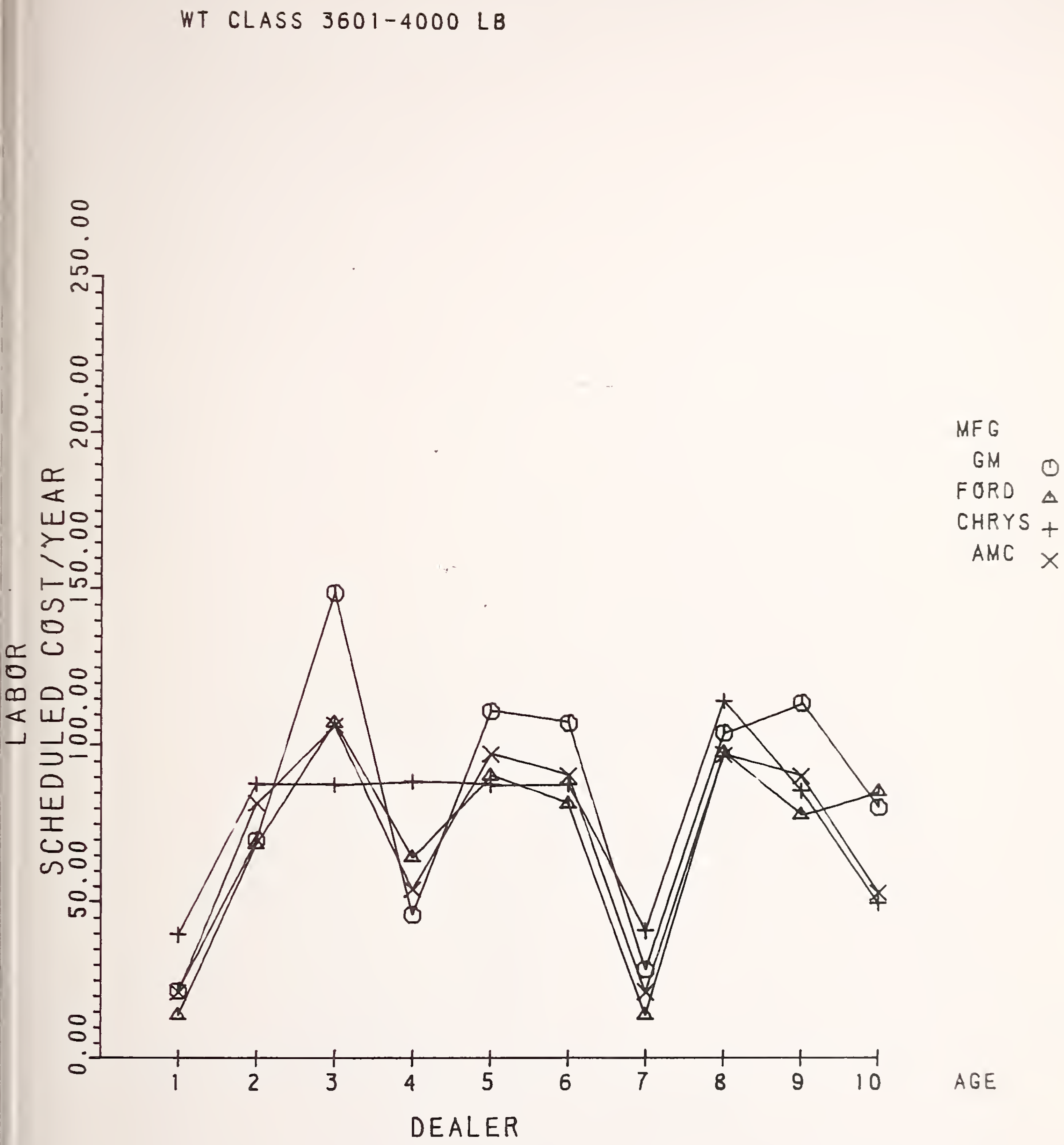

WT CLASS 3601-4000 LB
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-70

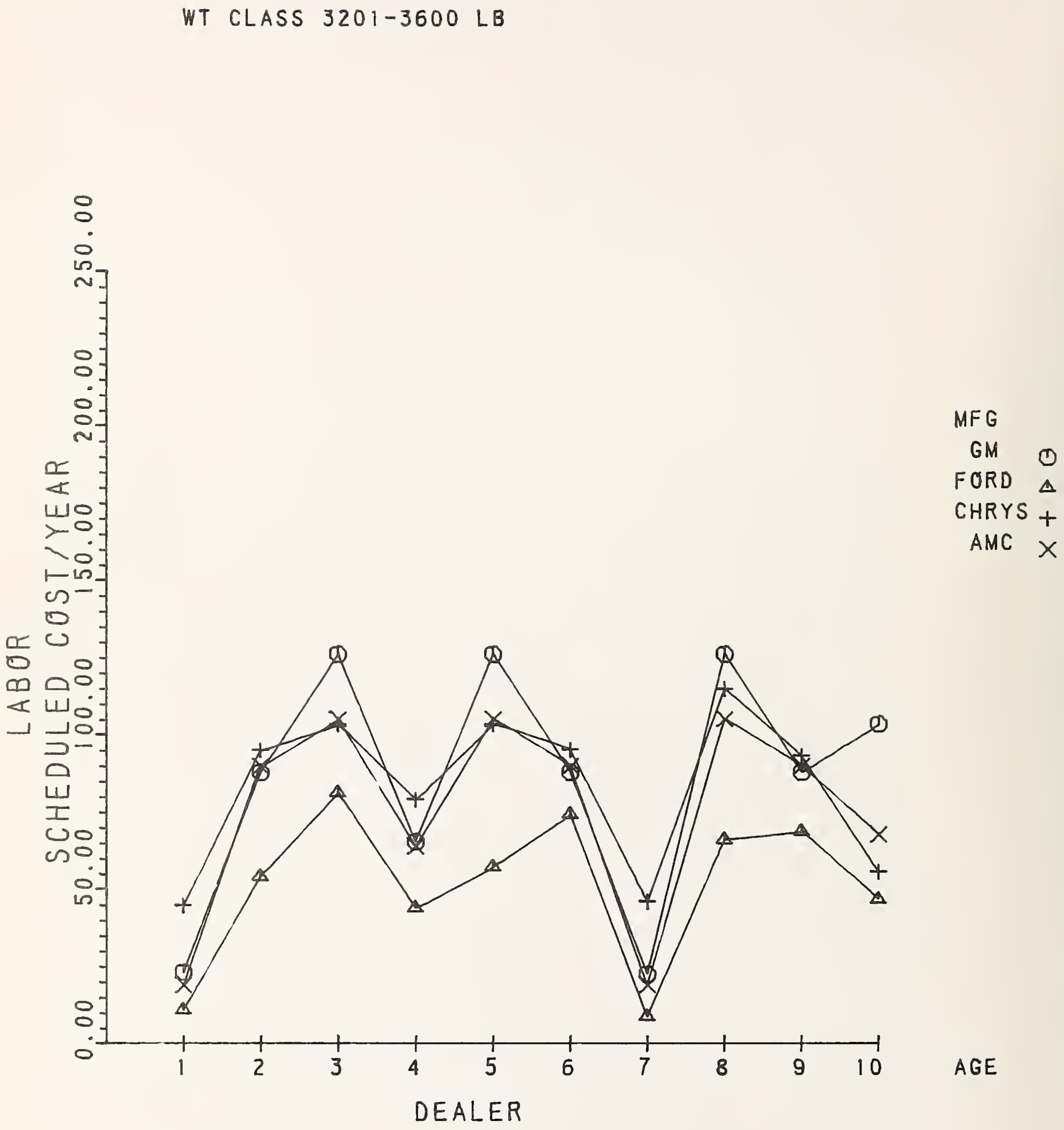

WT CLASS 3201-3600 LB
LABØR
SCHEDULED CØST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FØRD
CHRYS
AMC

FIGURE A-71

WT CLASS 2601-3200 LB

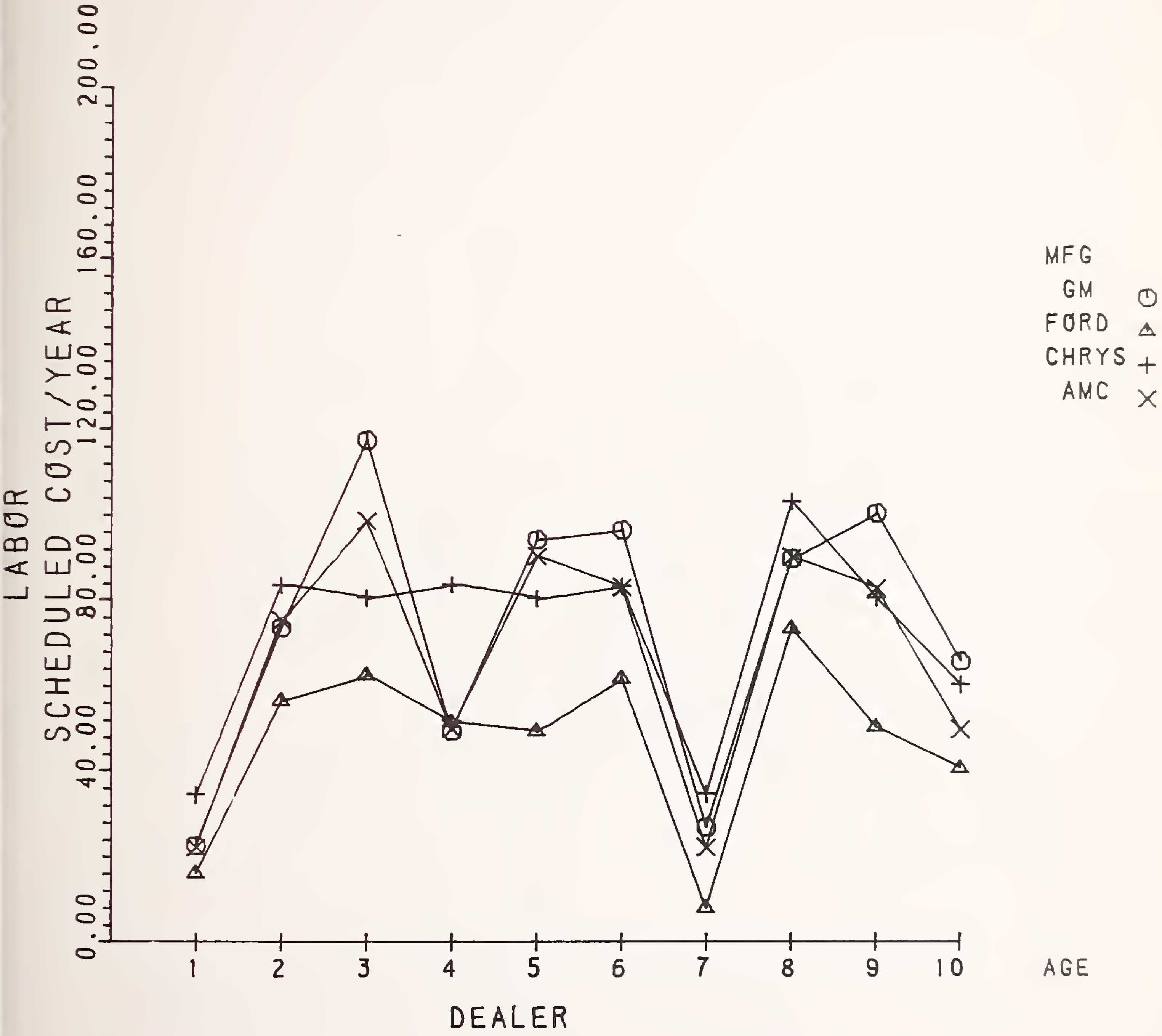


FIGURE A-72

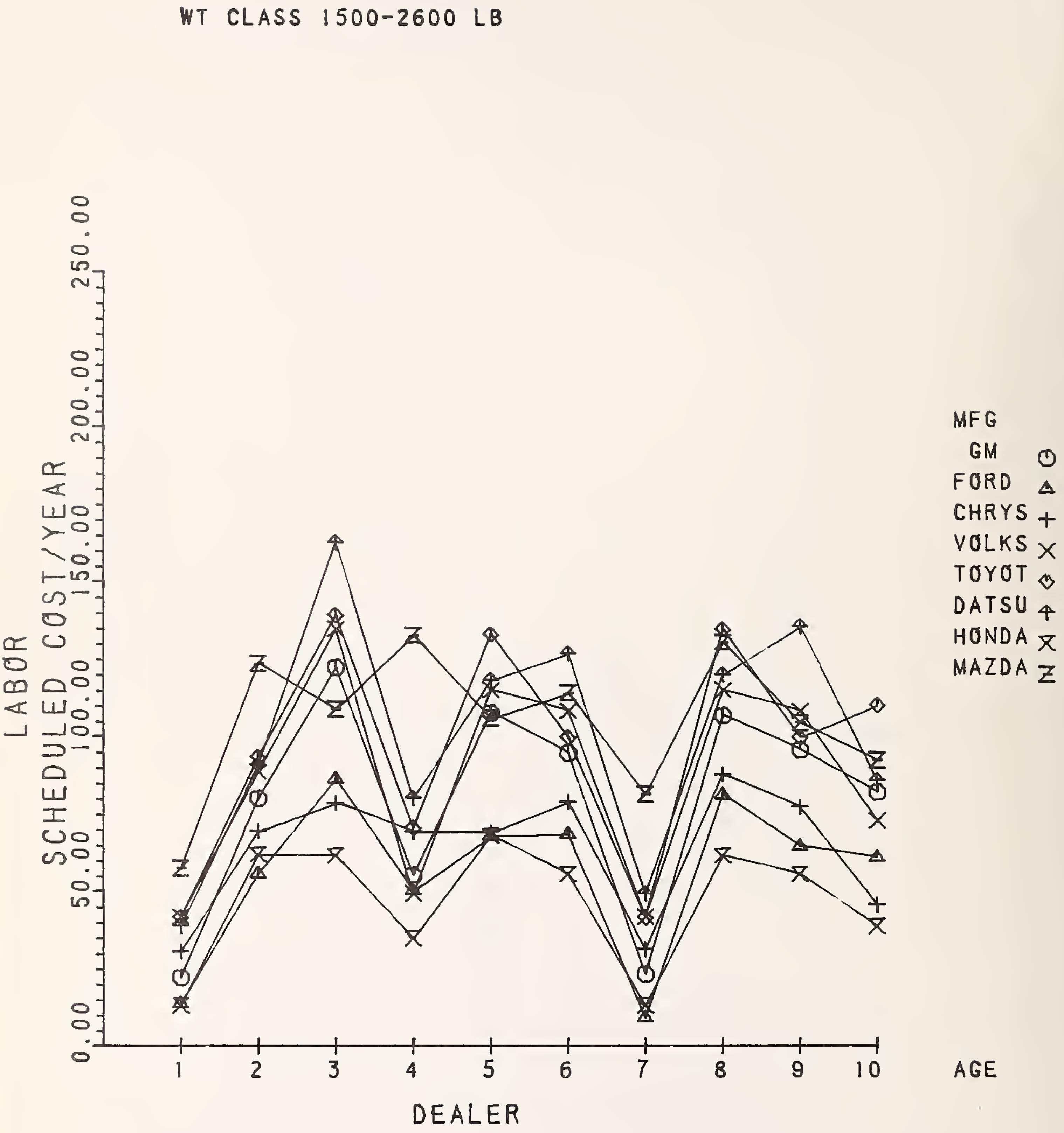

WT CLASS 1500-2600 LB
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
VOLKS ×
TOYOT ◇
DATSU ↑
HONDA ⧖
MAZDA Z

FIGURE A-73

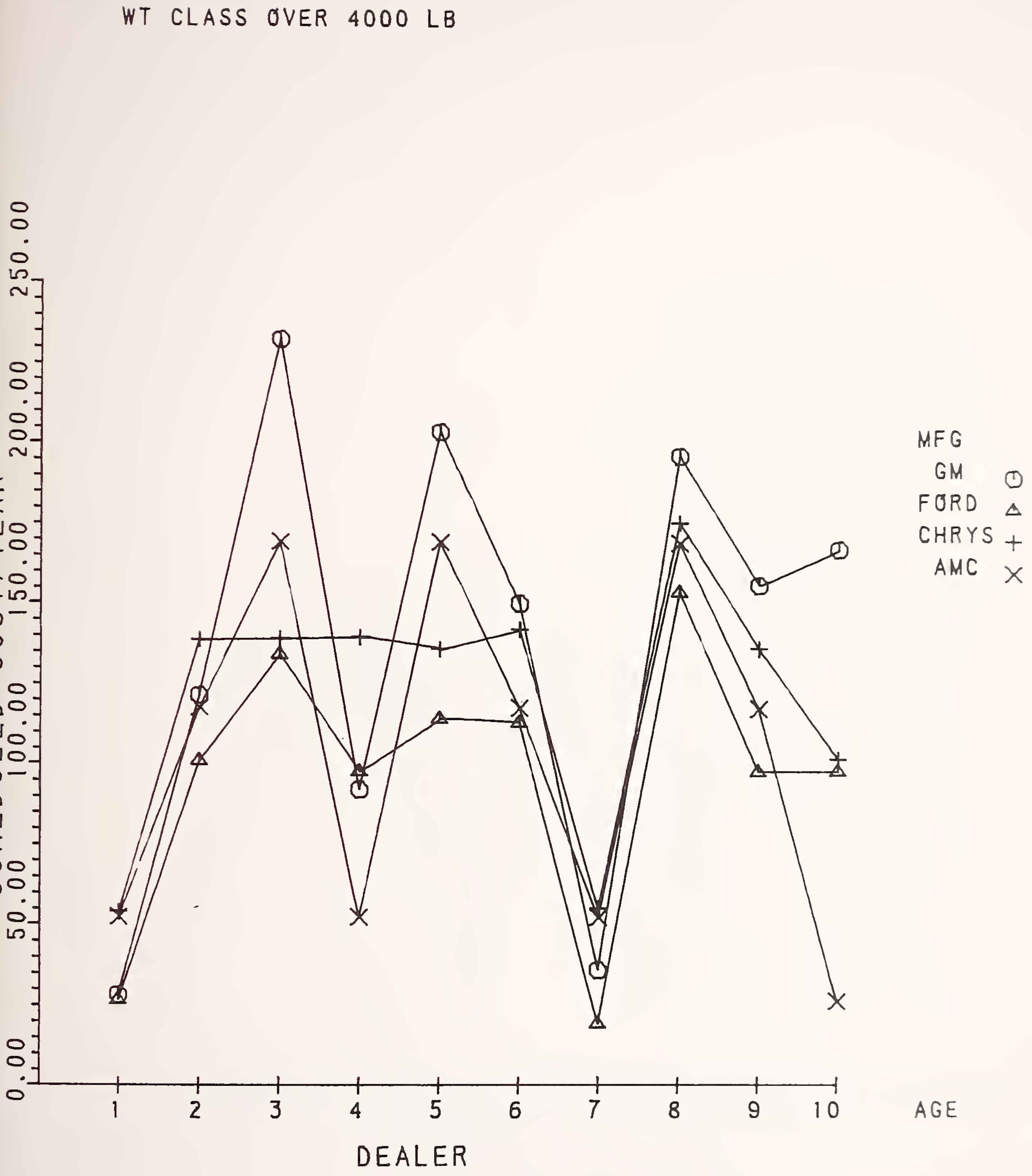

WT CLASS OVER 4000 LB
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
AMC

FIGURE A-74

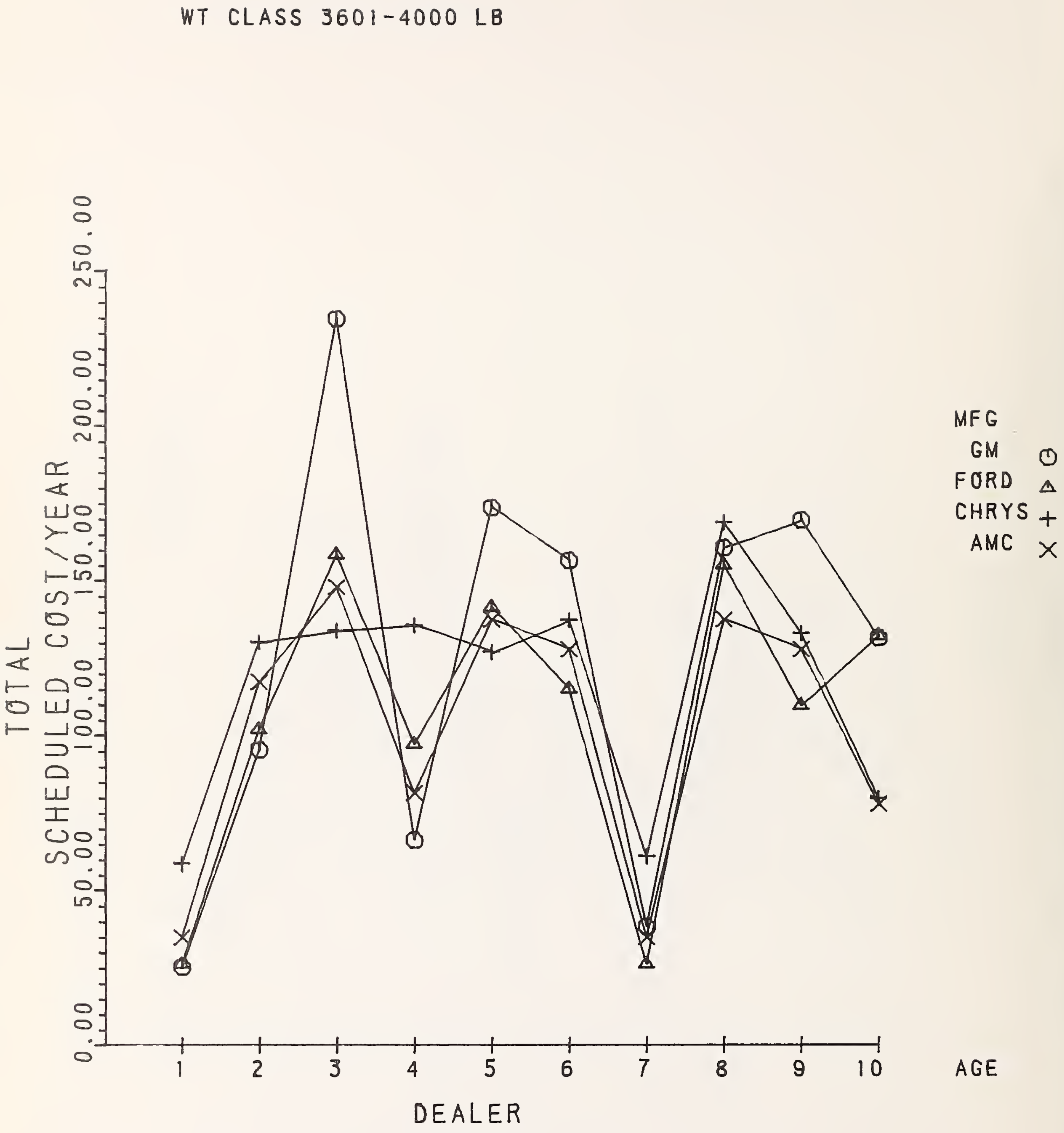

WT CLASS 3601-4000 LB
TØTAL
SCHEDULED CØST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ⌽
FØRD △
CHRYS +
AMC ×

FIGURE A-75

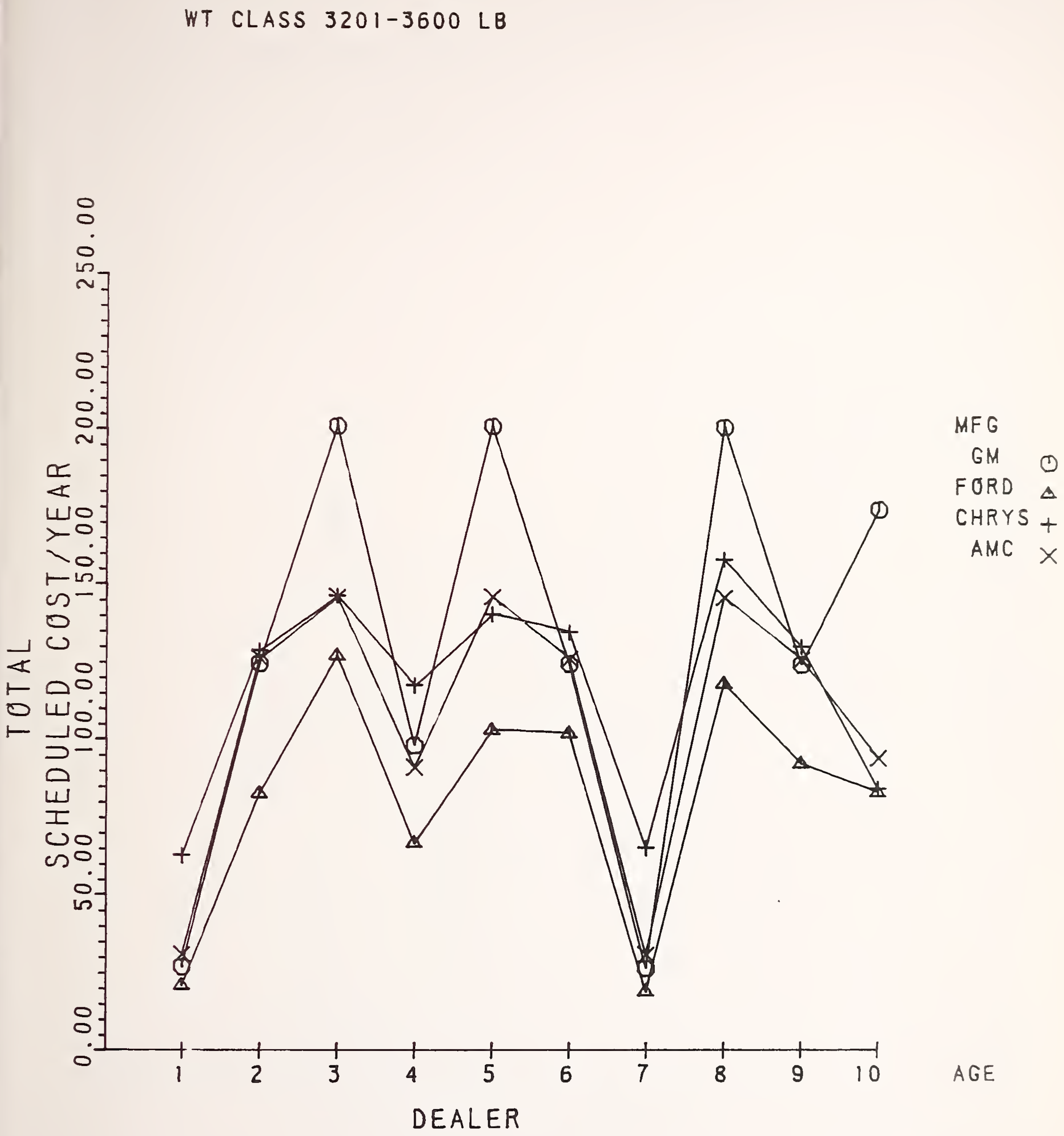

WT CLASS 3201-3600 LB
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
AMC

FIGURE A-76

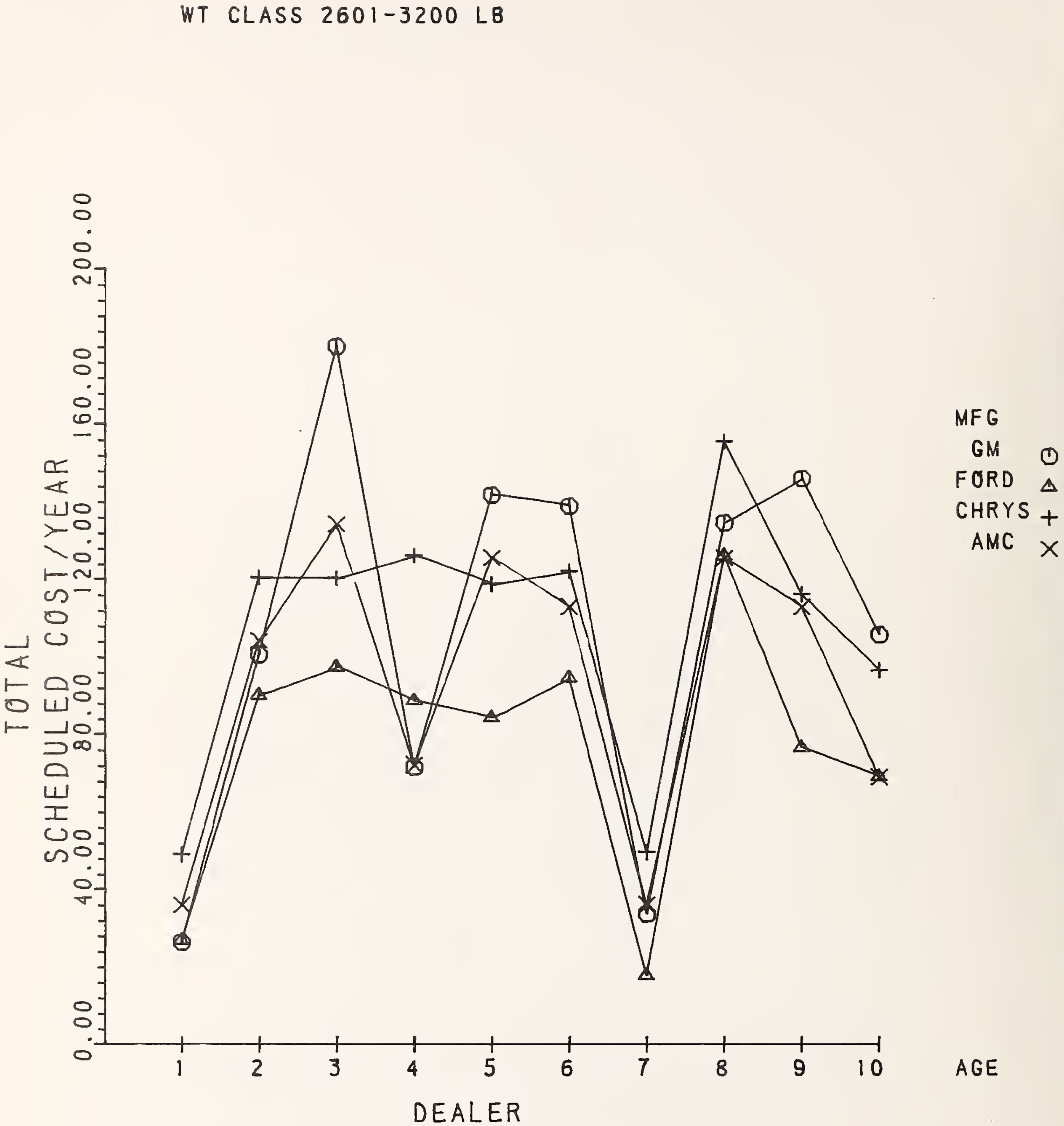

WT CLASS 2601-3200 LB
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ⊕
FORD △
CHRYS +
AMC ×

FIGURE A-77

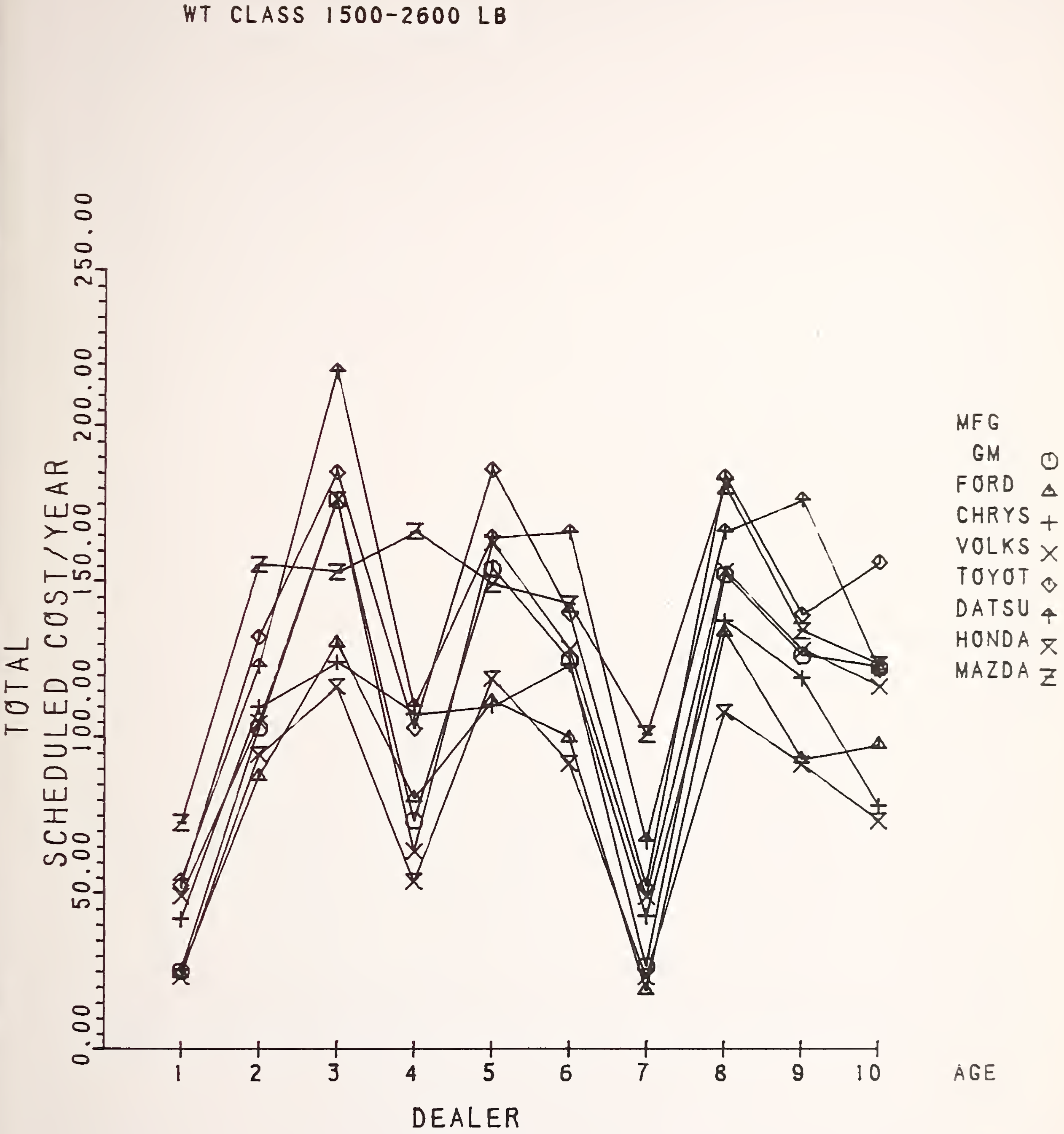

WT CLASS 1500-2600 LB
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
VOLKS
TOYOT
DATSU
HONDA
MAZDA

FIGURE A-78

ENG. DISP. > 371

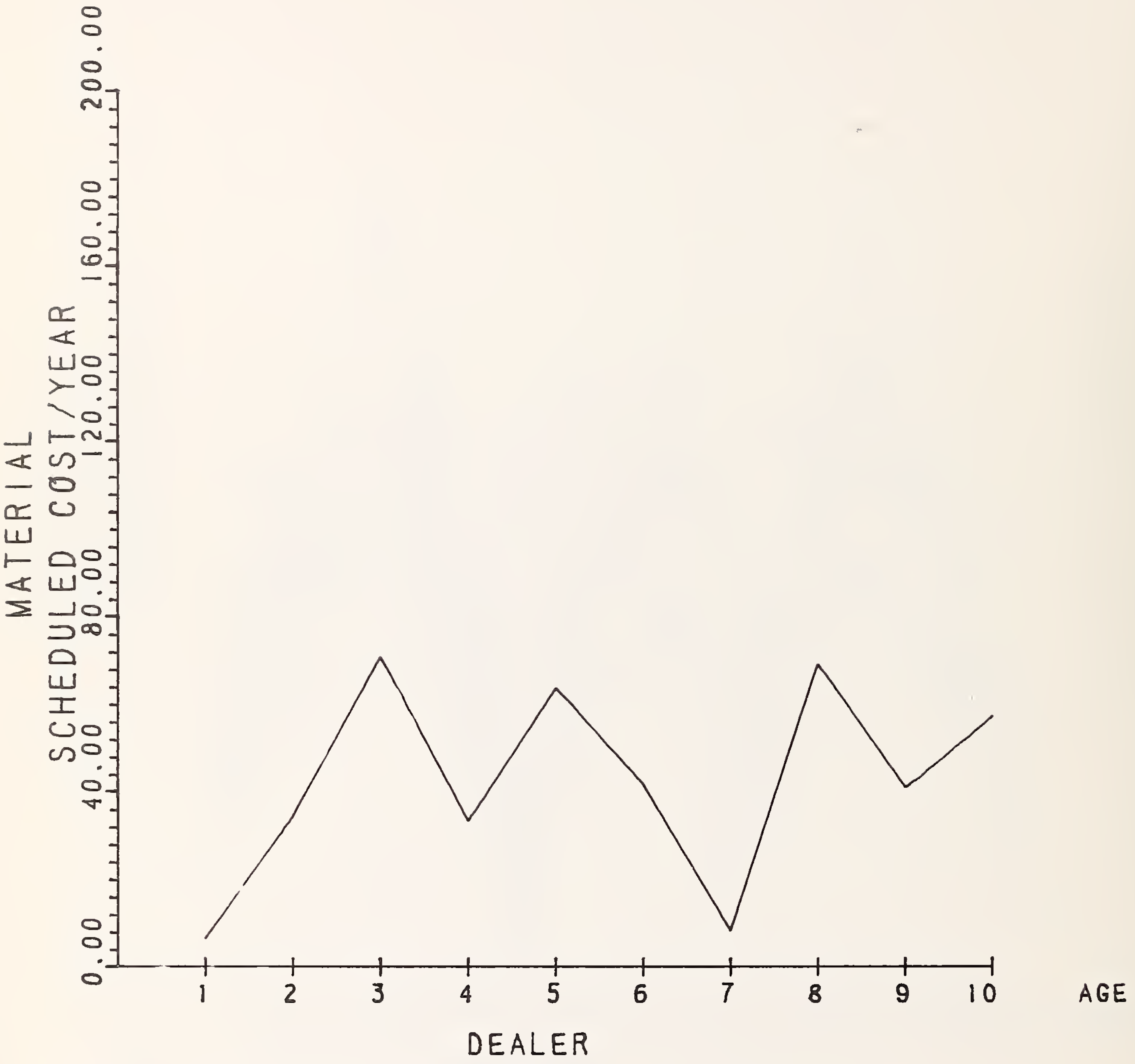


FIGURE A-79

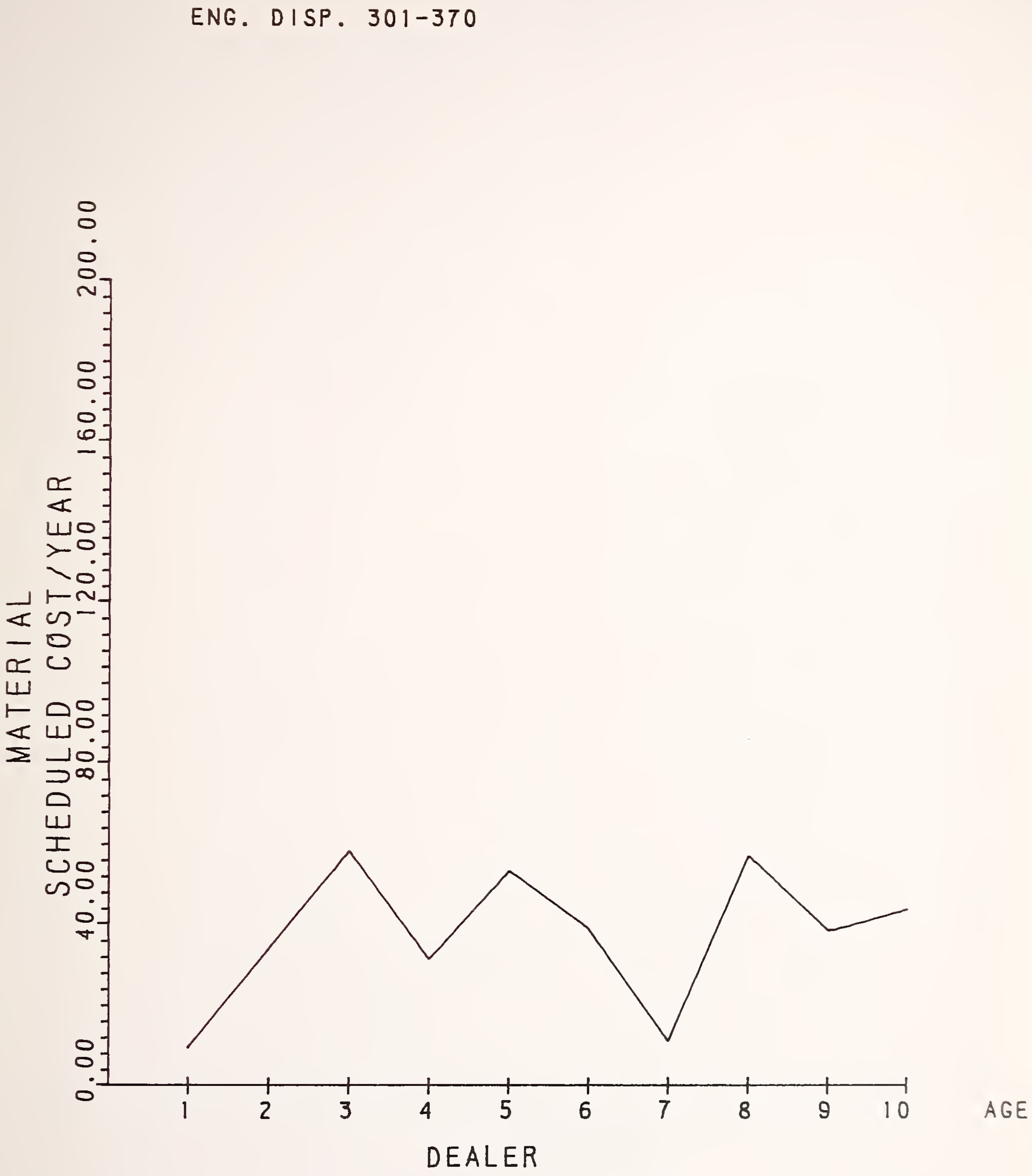

ENG. DISP. 301-370
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-80

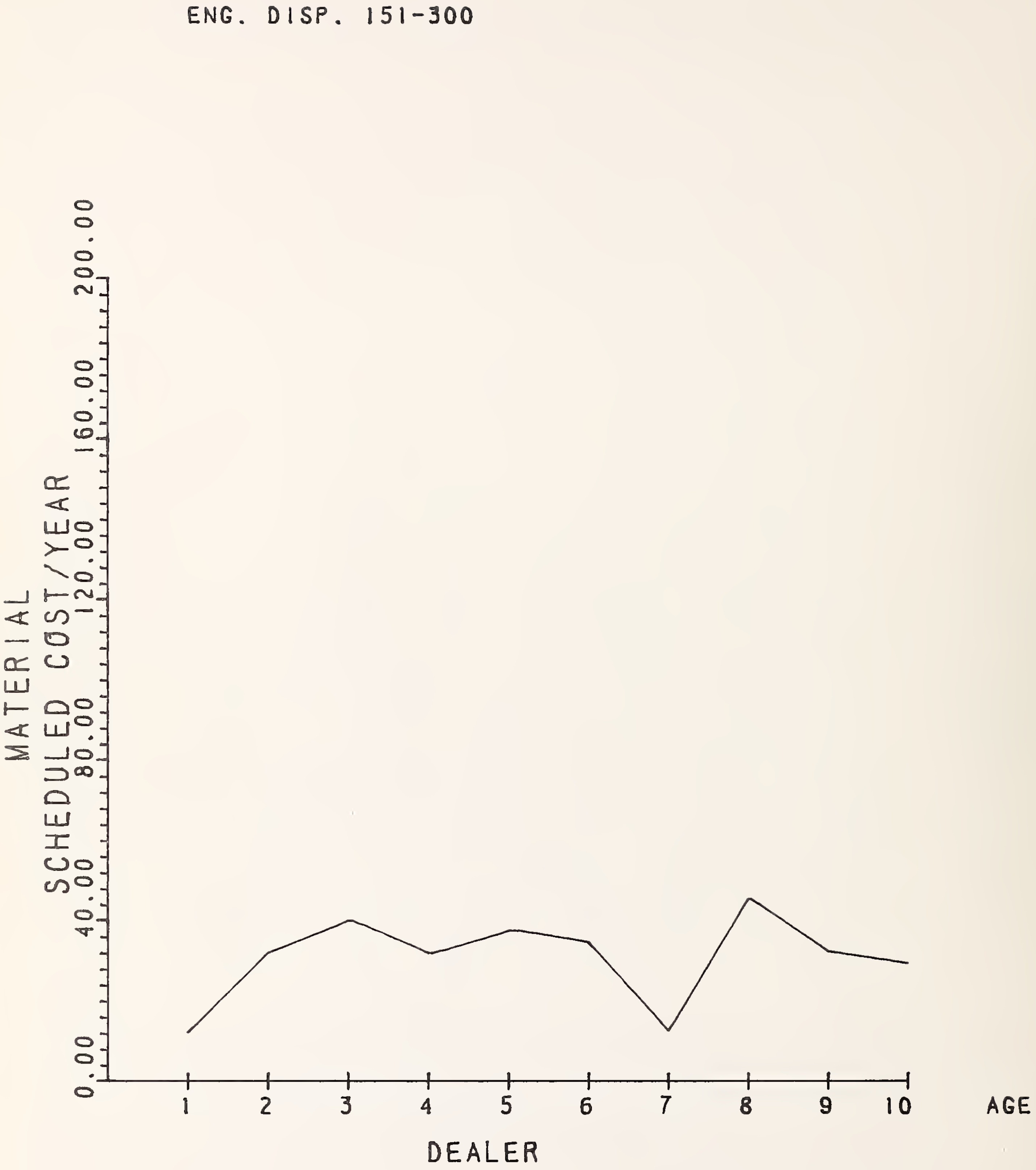
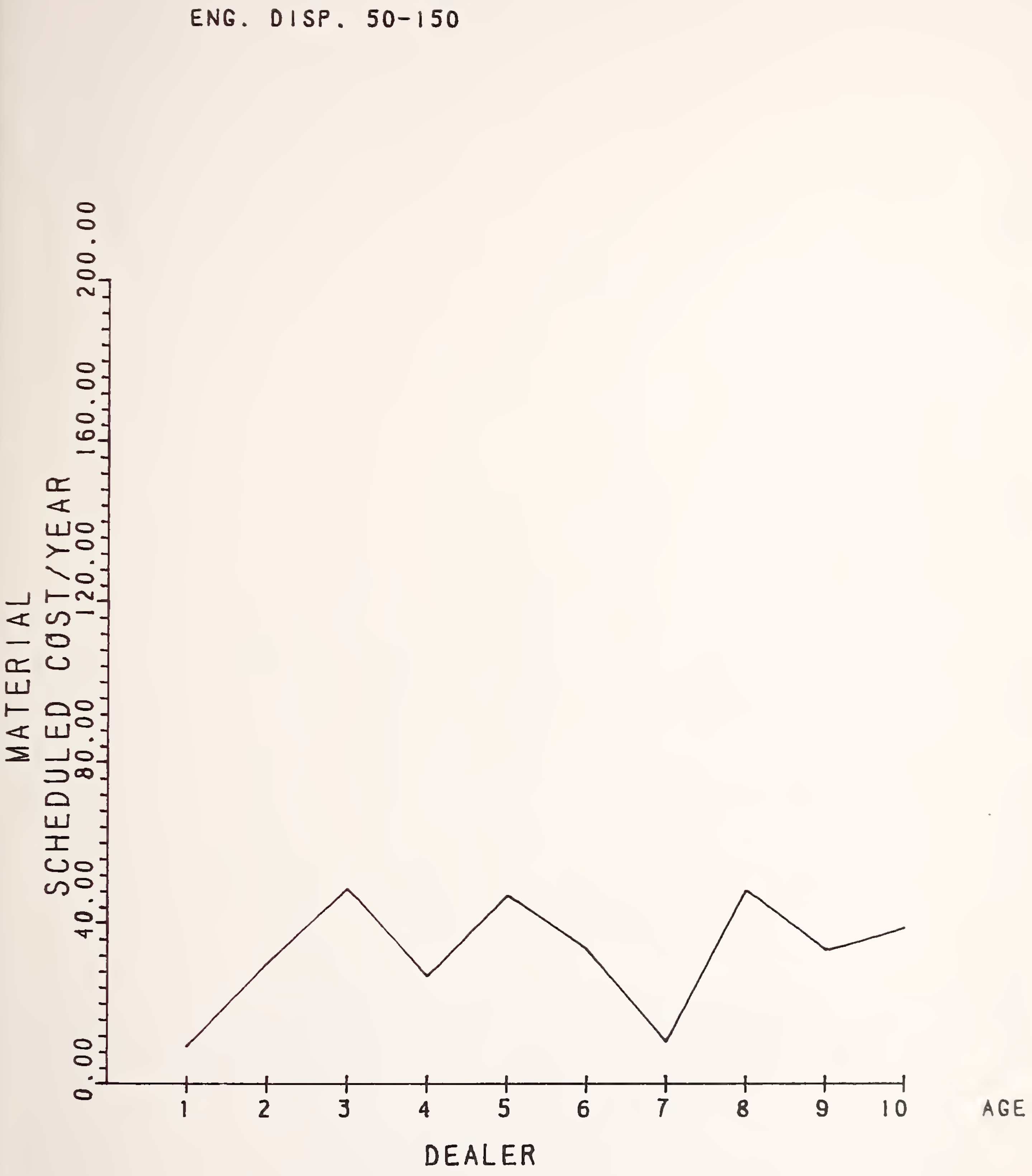

ENG. DISP. 151-300
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-81



ENG. DISP. 50-150
MATERIAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-82

ENG. DISP. > 371

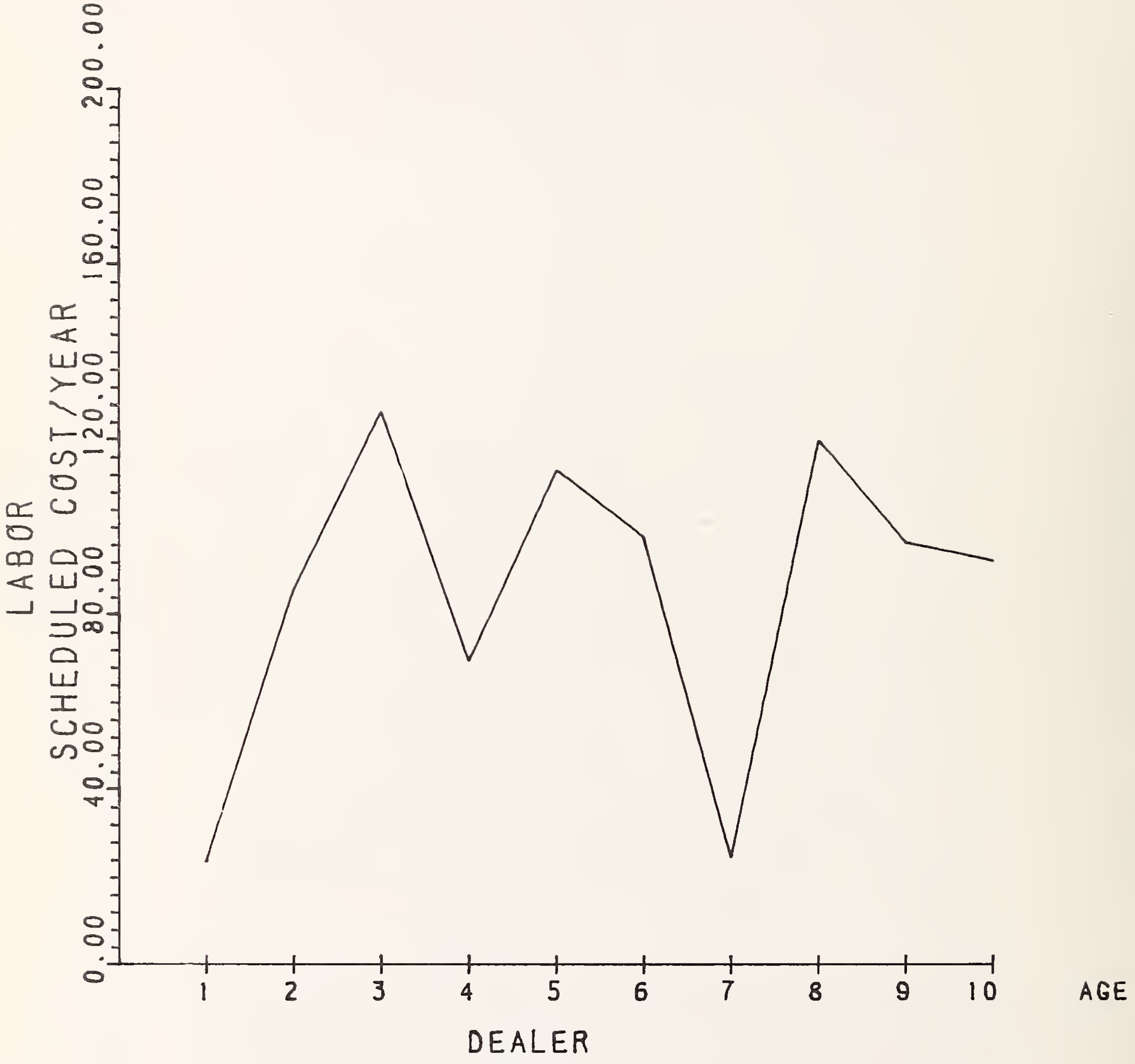


FIGURE A-83

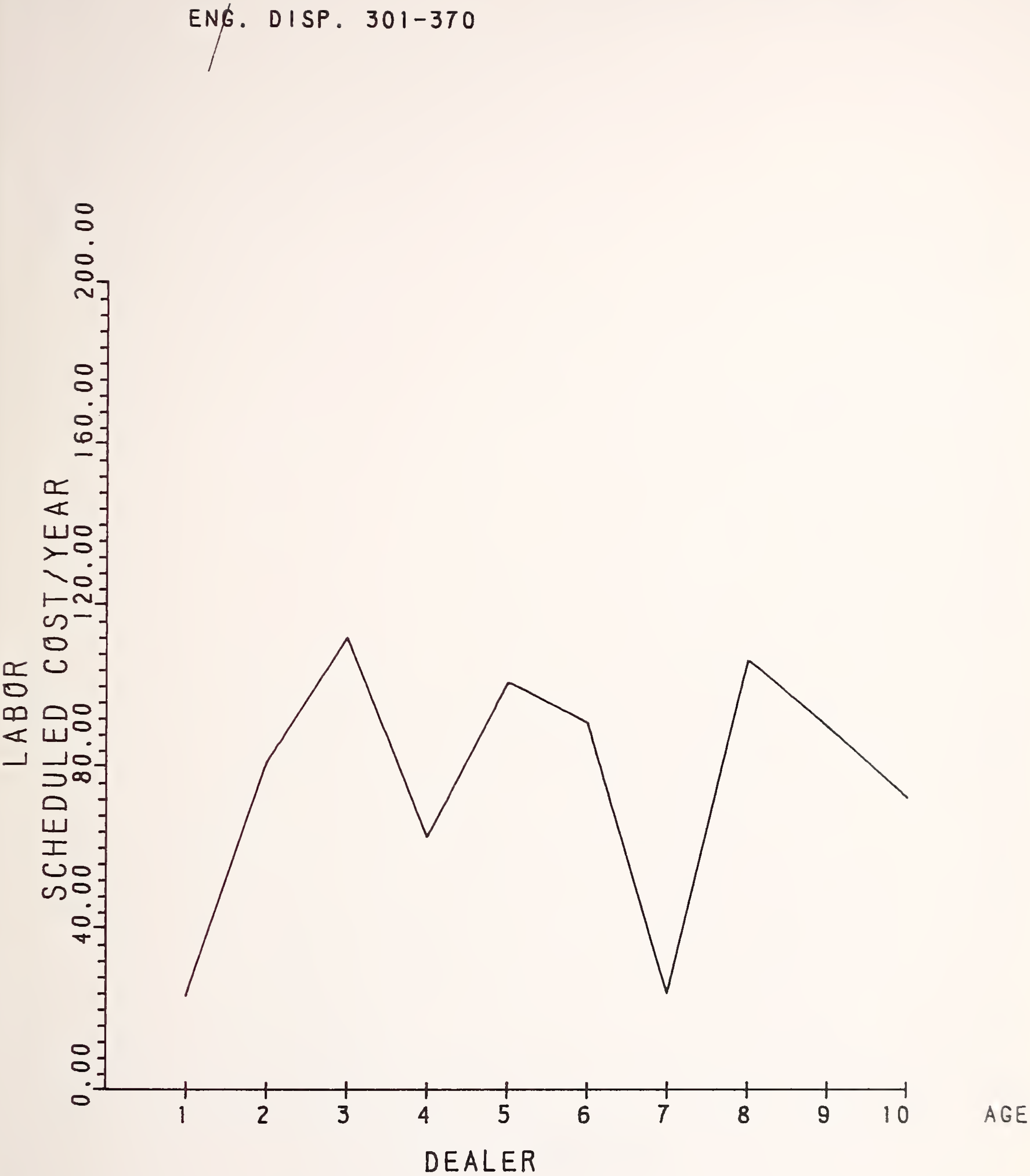

ENG. DISP. 301-370
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-84

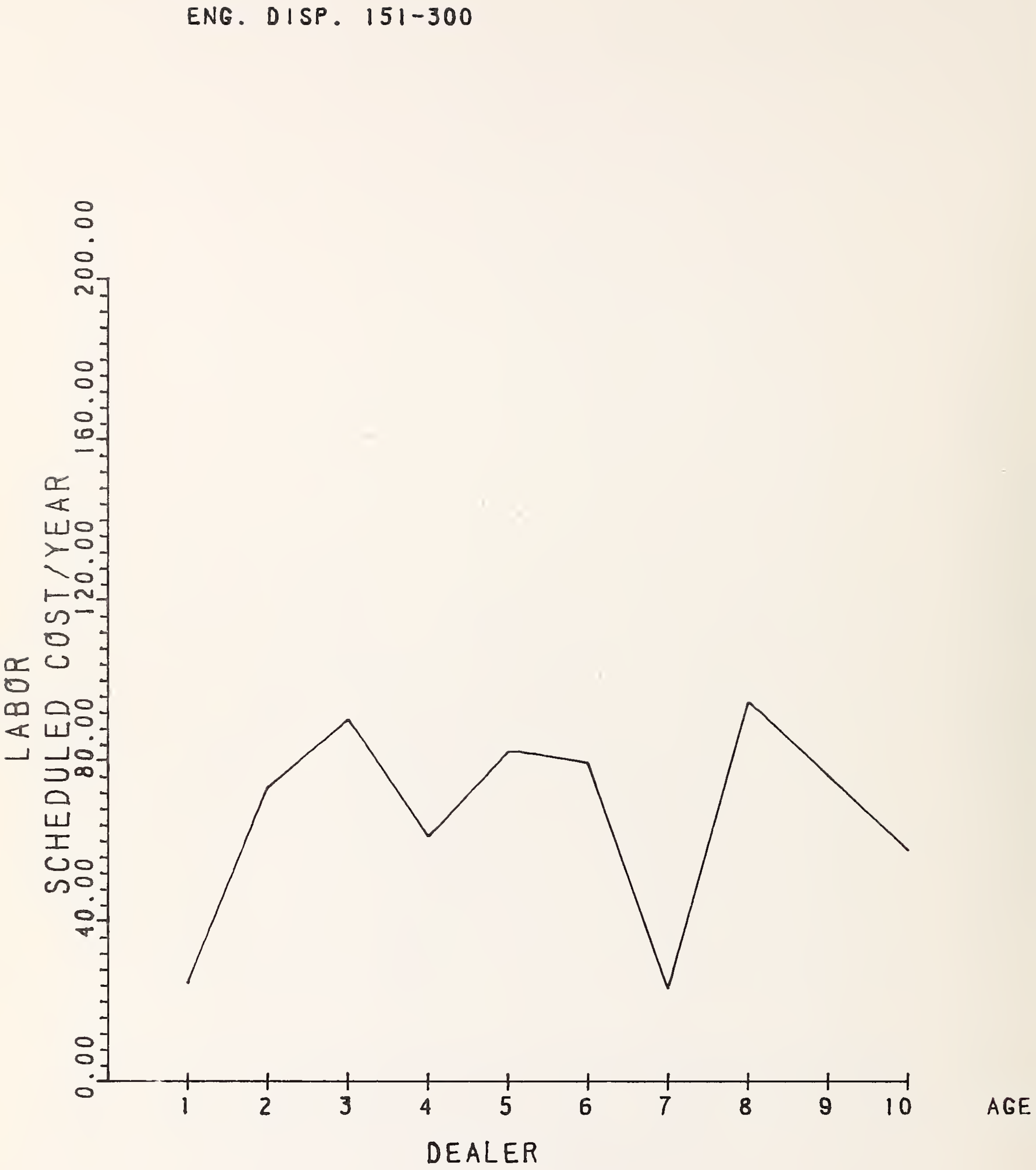

ENG. DISP. 151-300
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-85

ENG. DISP. 50-150

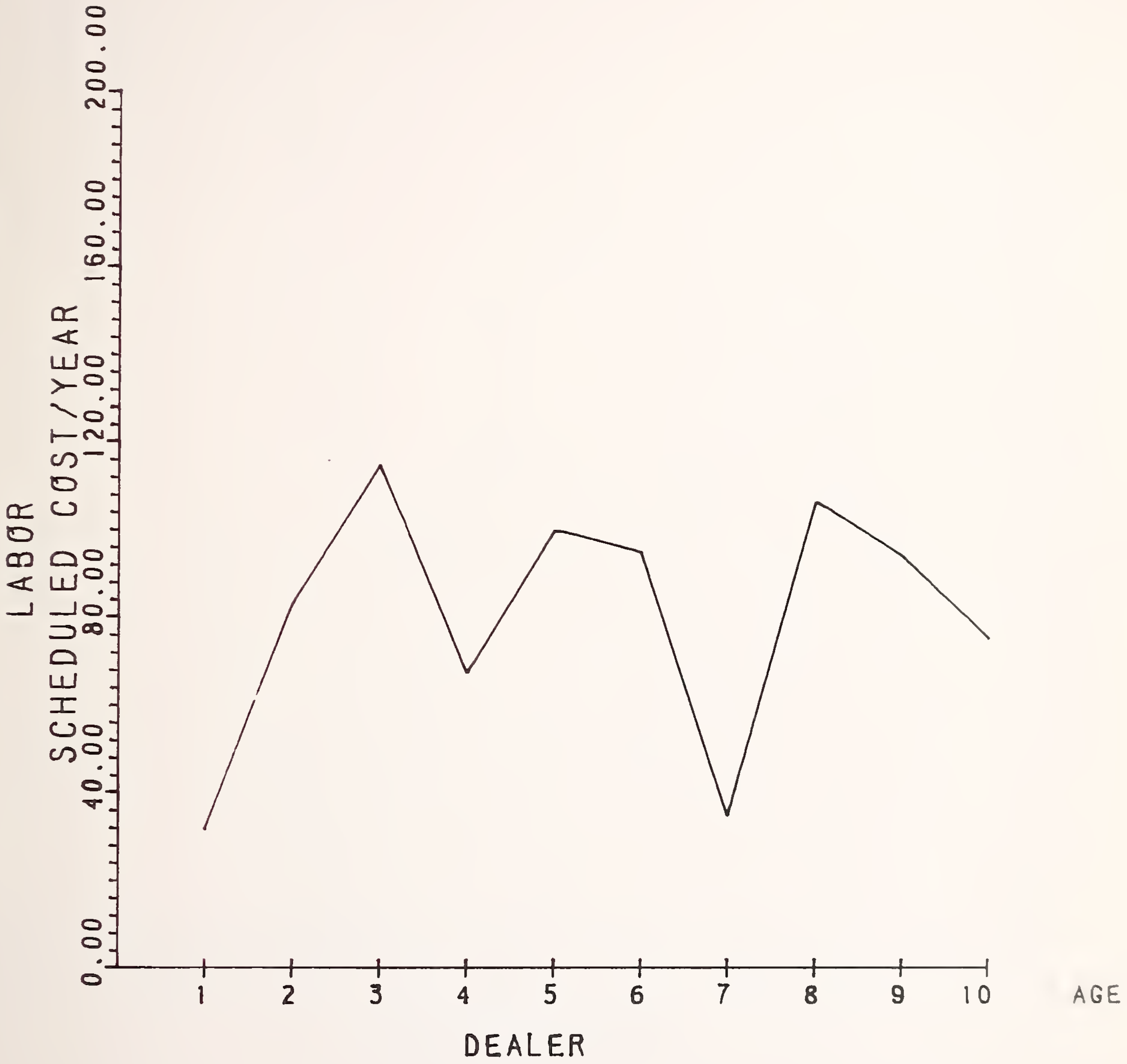


FIGURE A-86

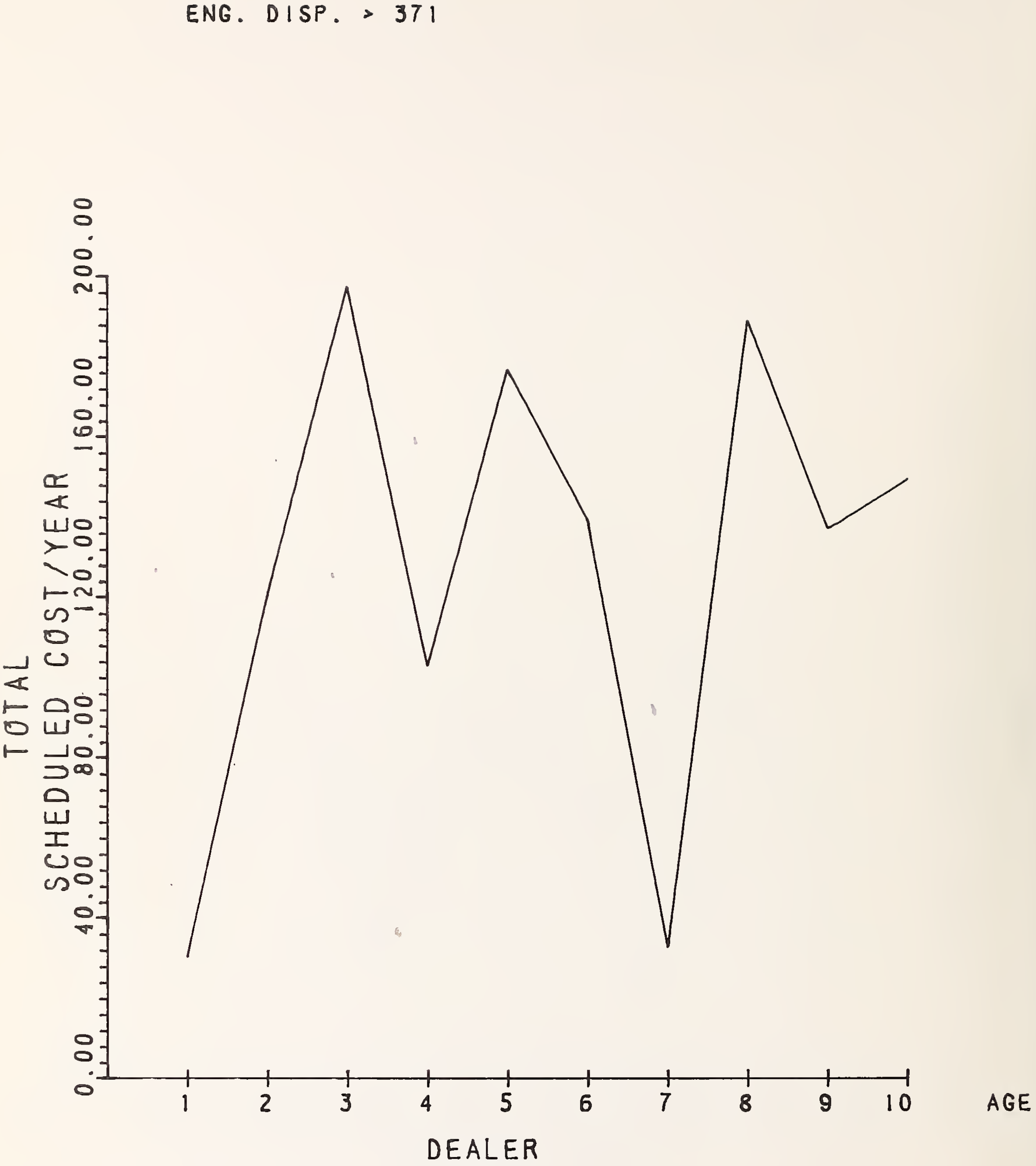

ENG. DISP. > 371
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-87

ENG. DISP. 151-300

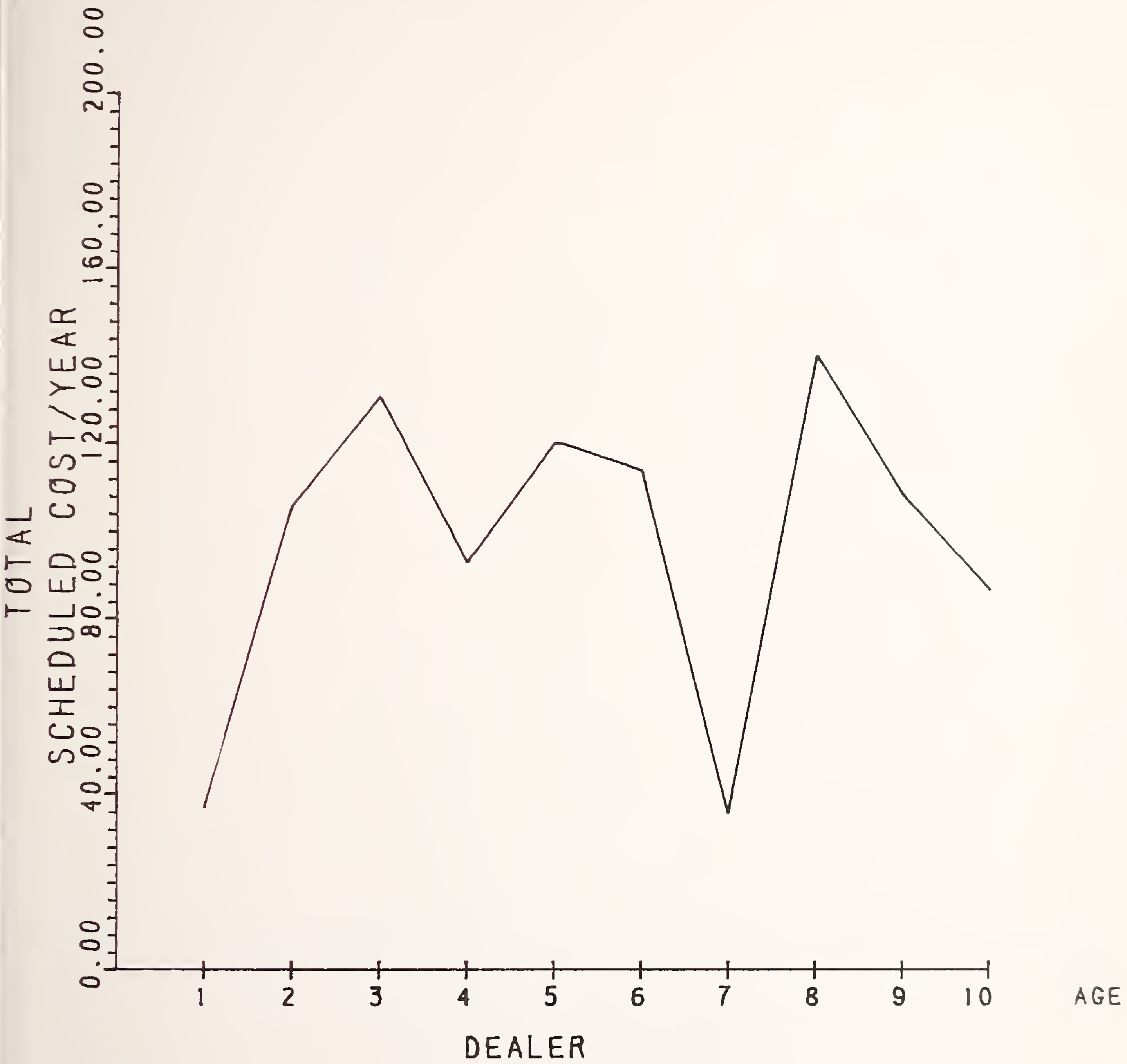


FIGURE A-88

ENG. DISP. 301-370

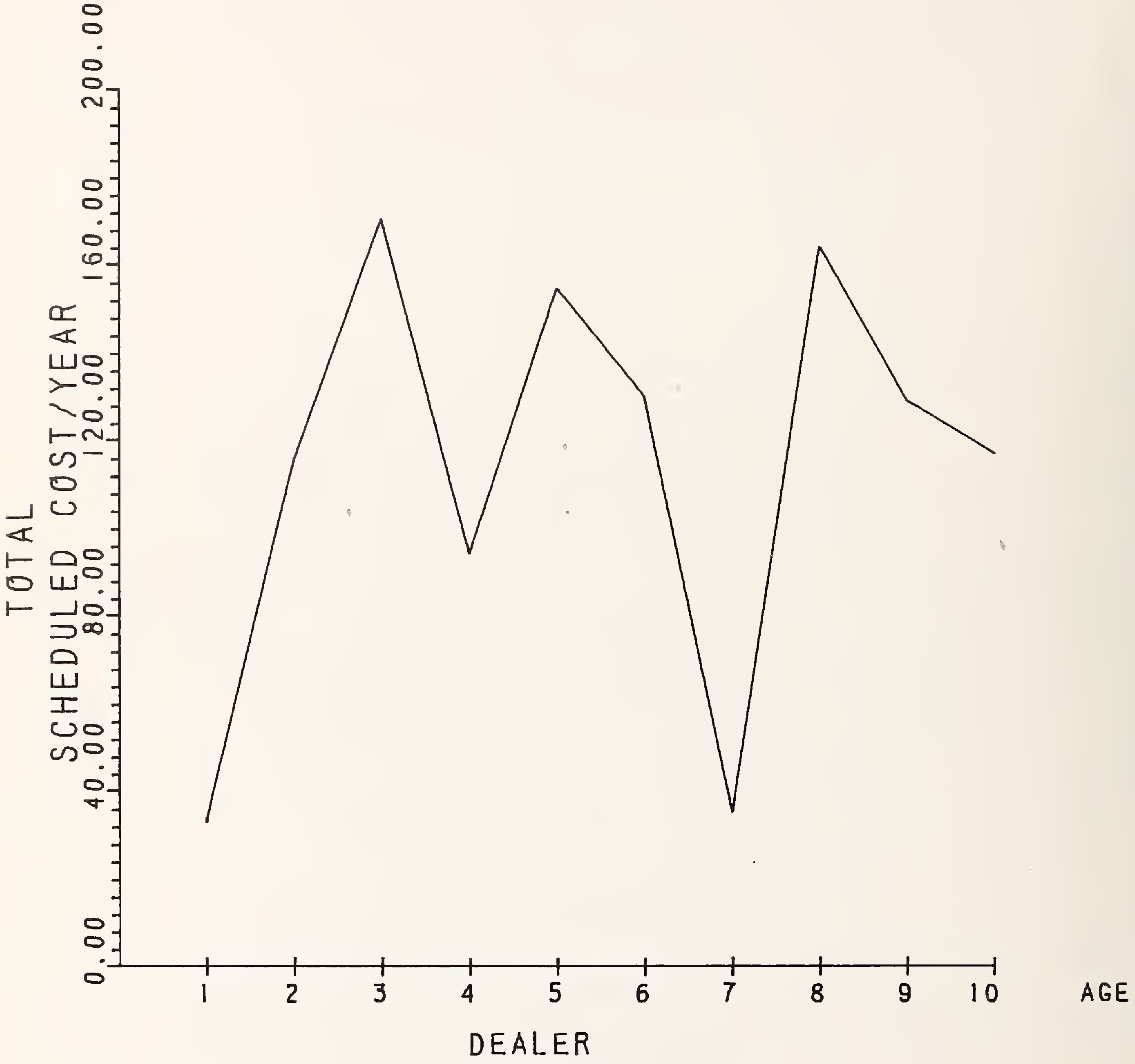


FIGURE A-89

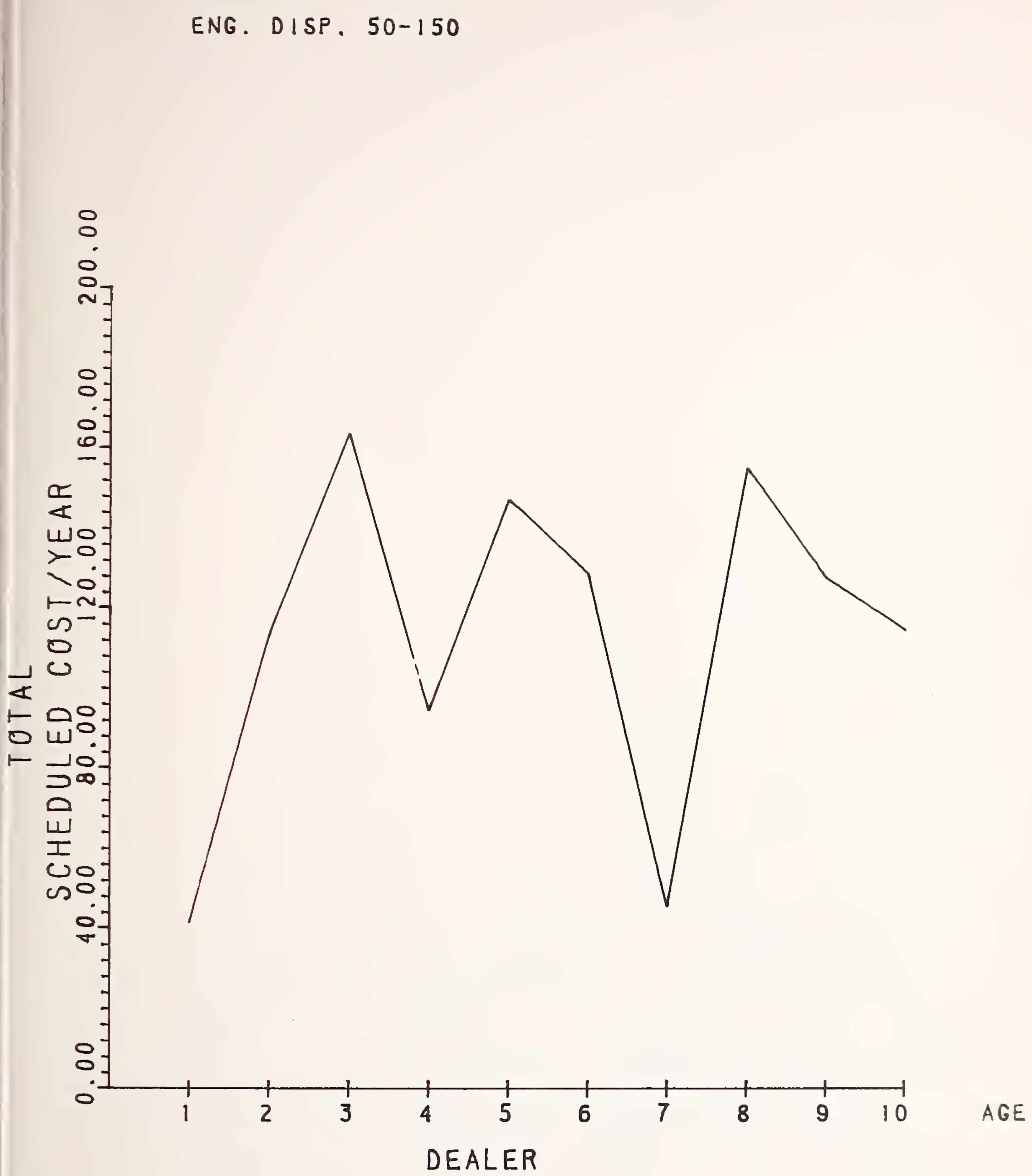

ENG. DISP. 50-150
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-90

ENG. DISP. > 371

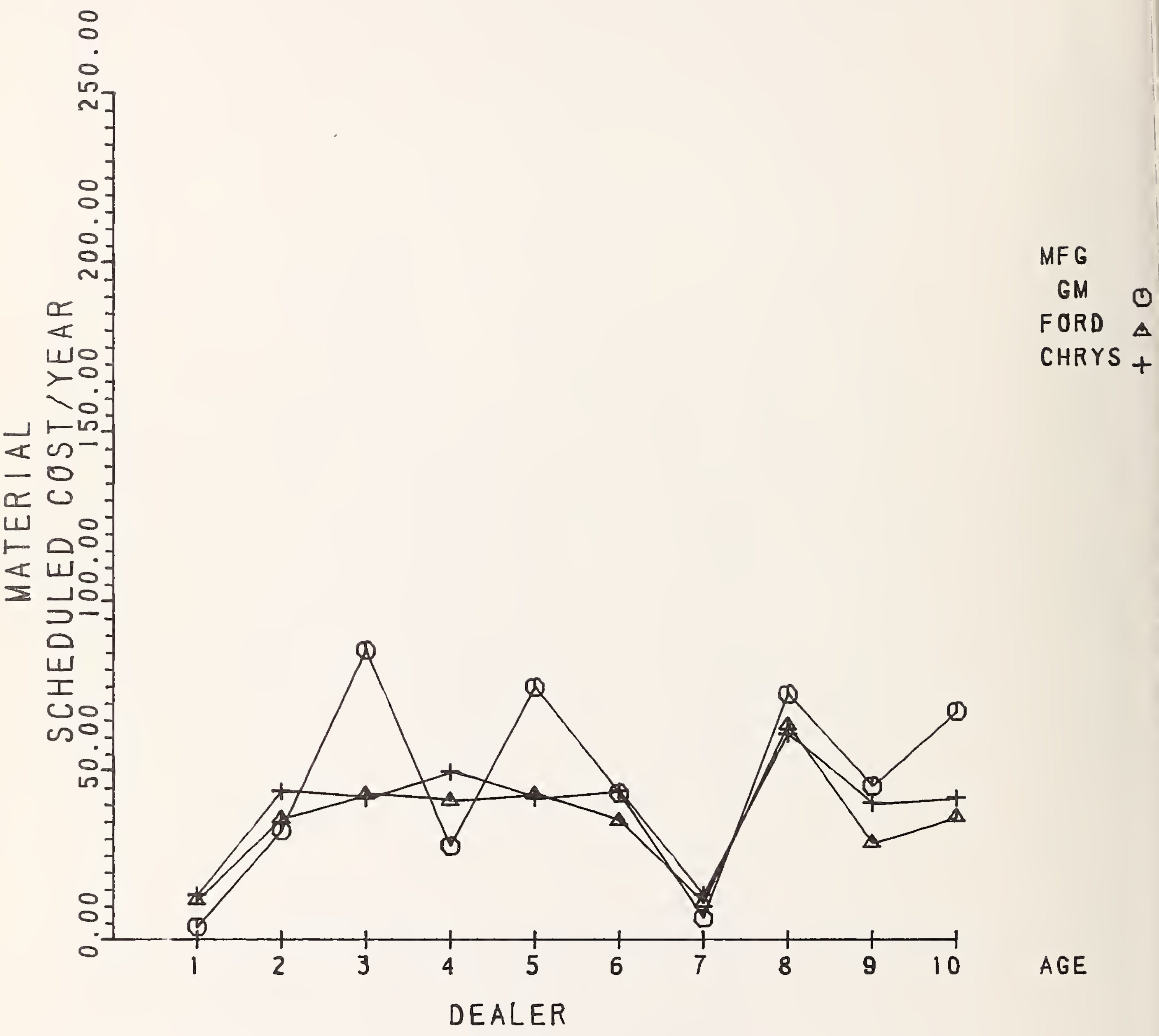


FIGURE A-91

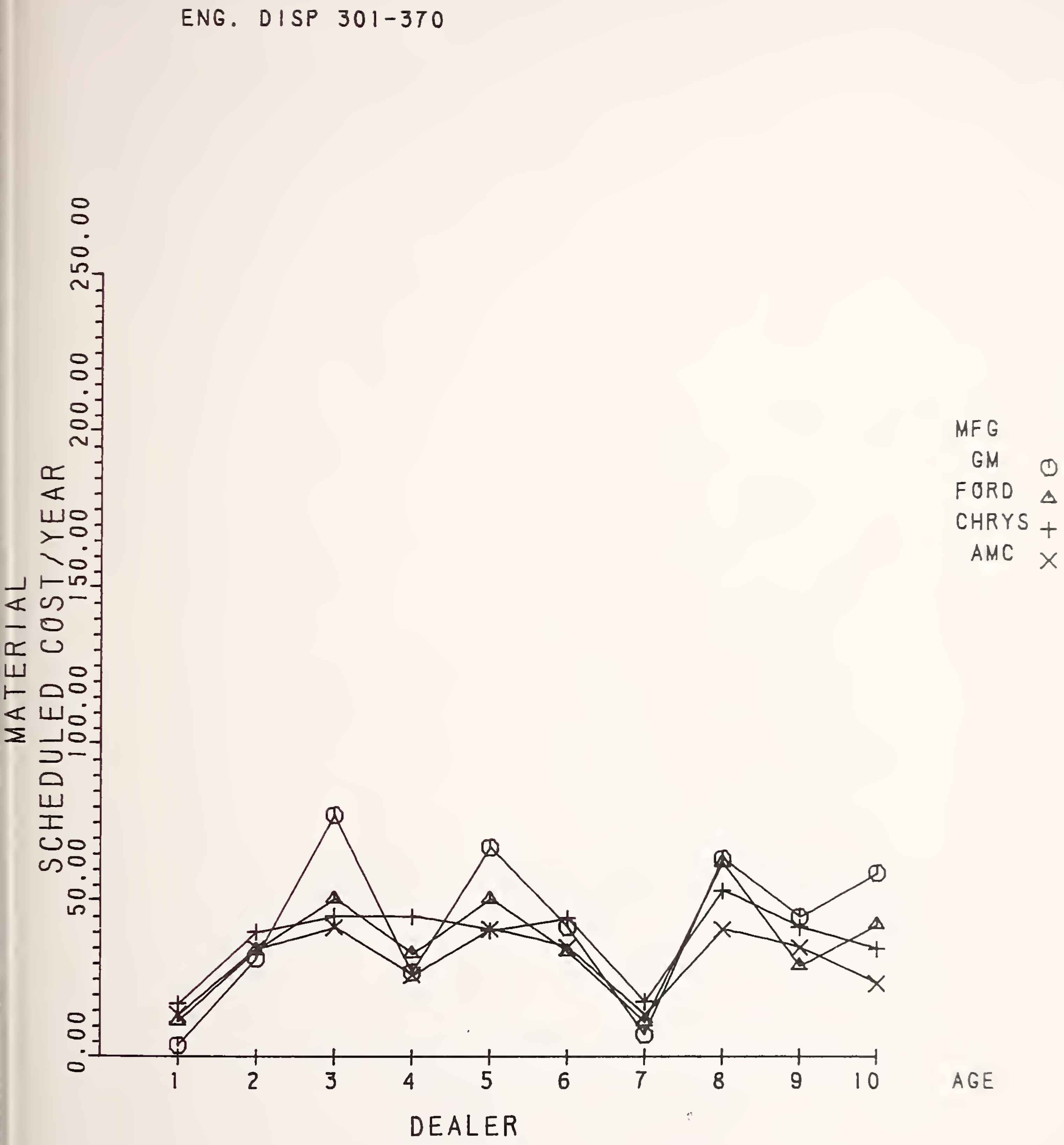

ENG. DISP 301-370
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FORD
CHRYS
AMC

FIGURE A-92

ENG. DISP. 151-300

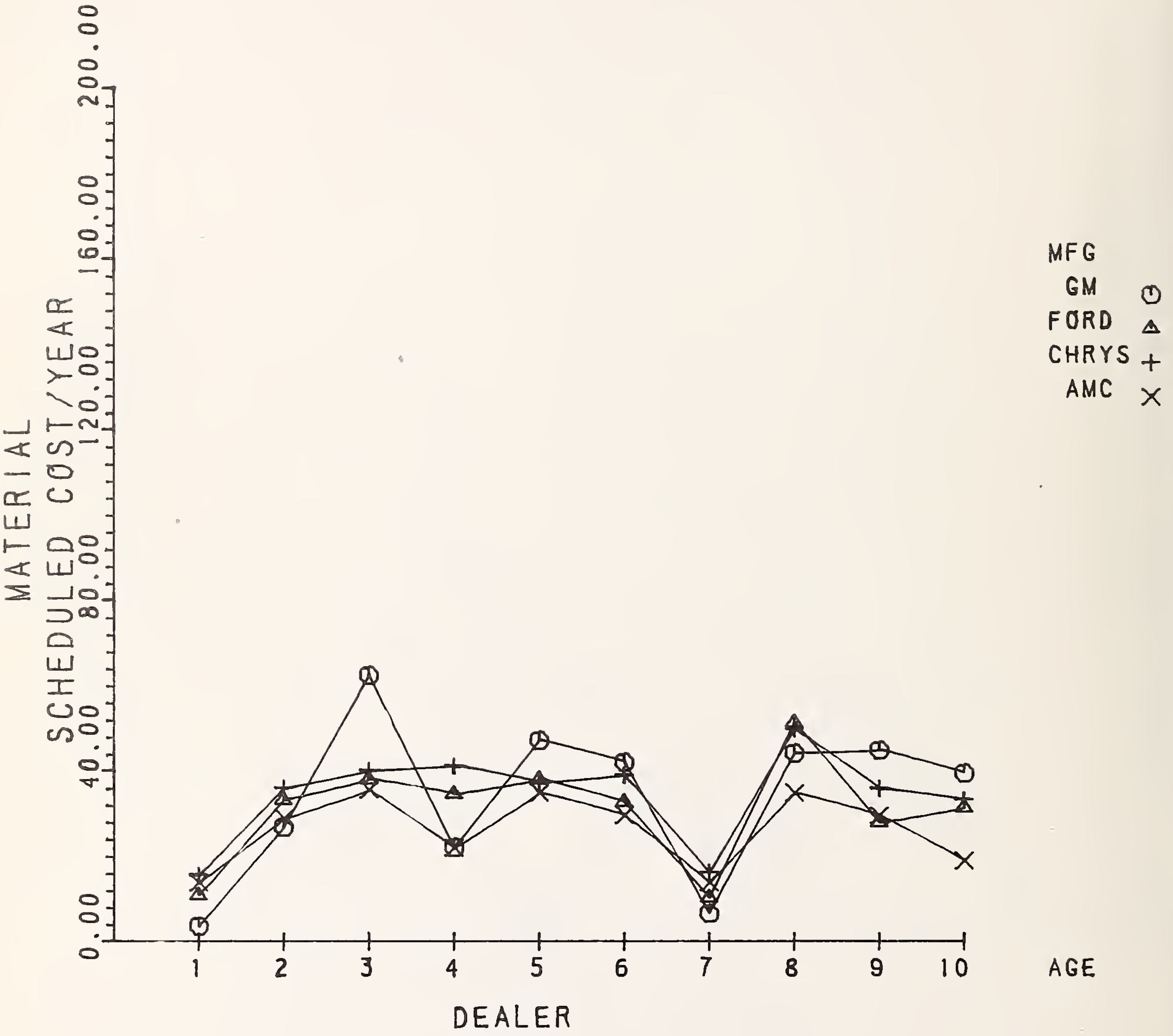


FIGURE A-93

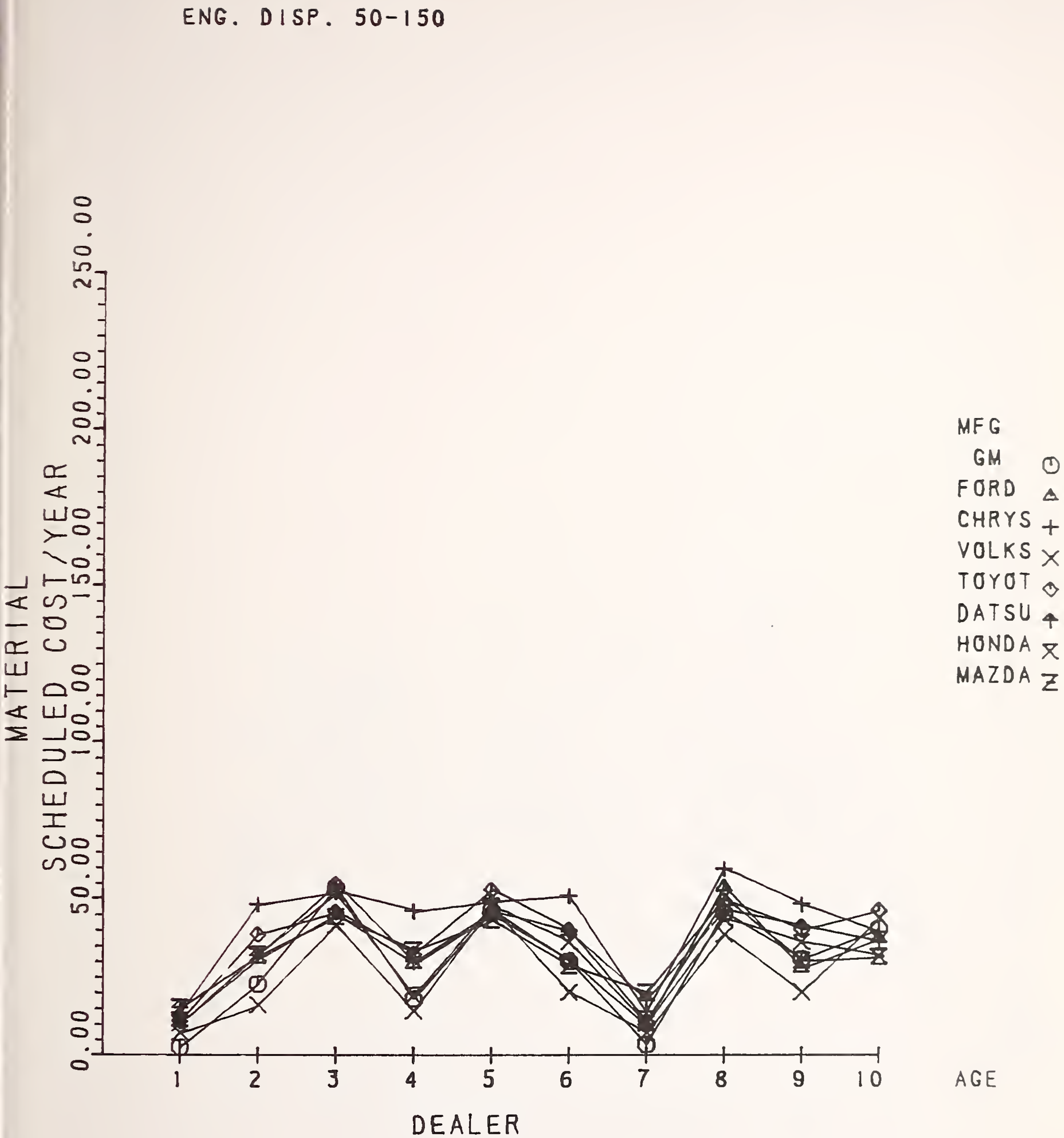

ENG. DISP. 50-150
MATERIAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
VOLKS ×
TOYOT ◇
DATSU
HONDA
MAZDA

FIGURE A-94

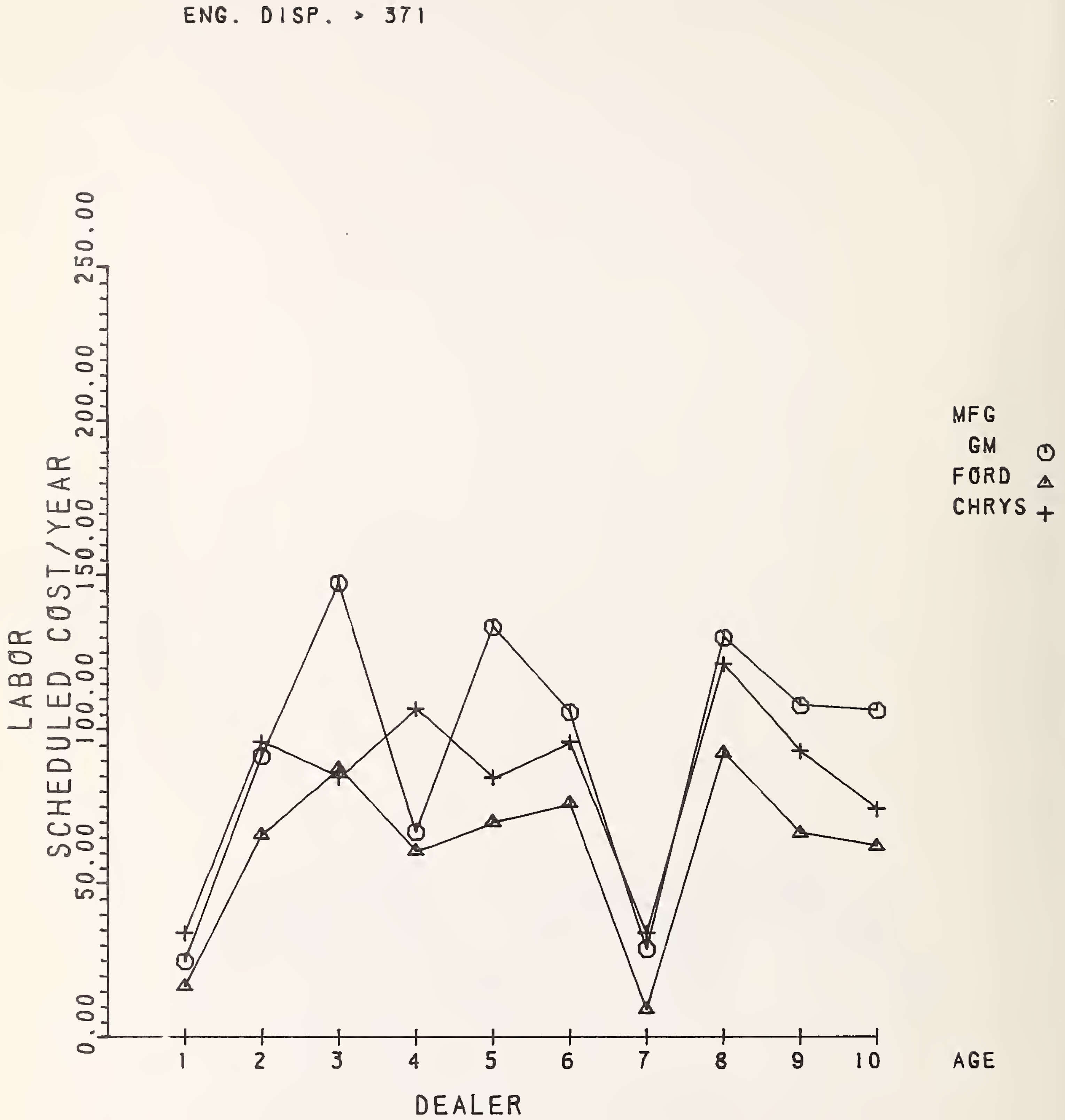

ENG. DISP. > 371
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +

FIGURE A-95

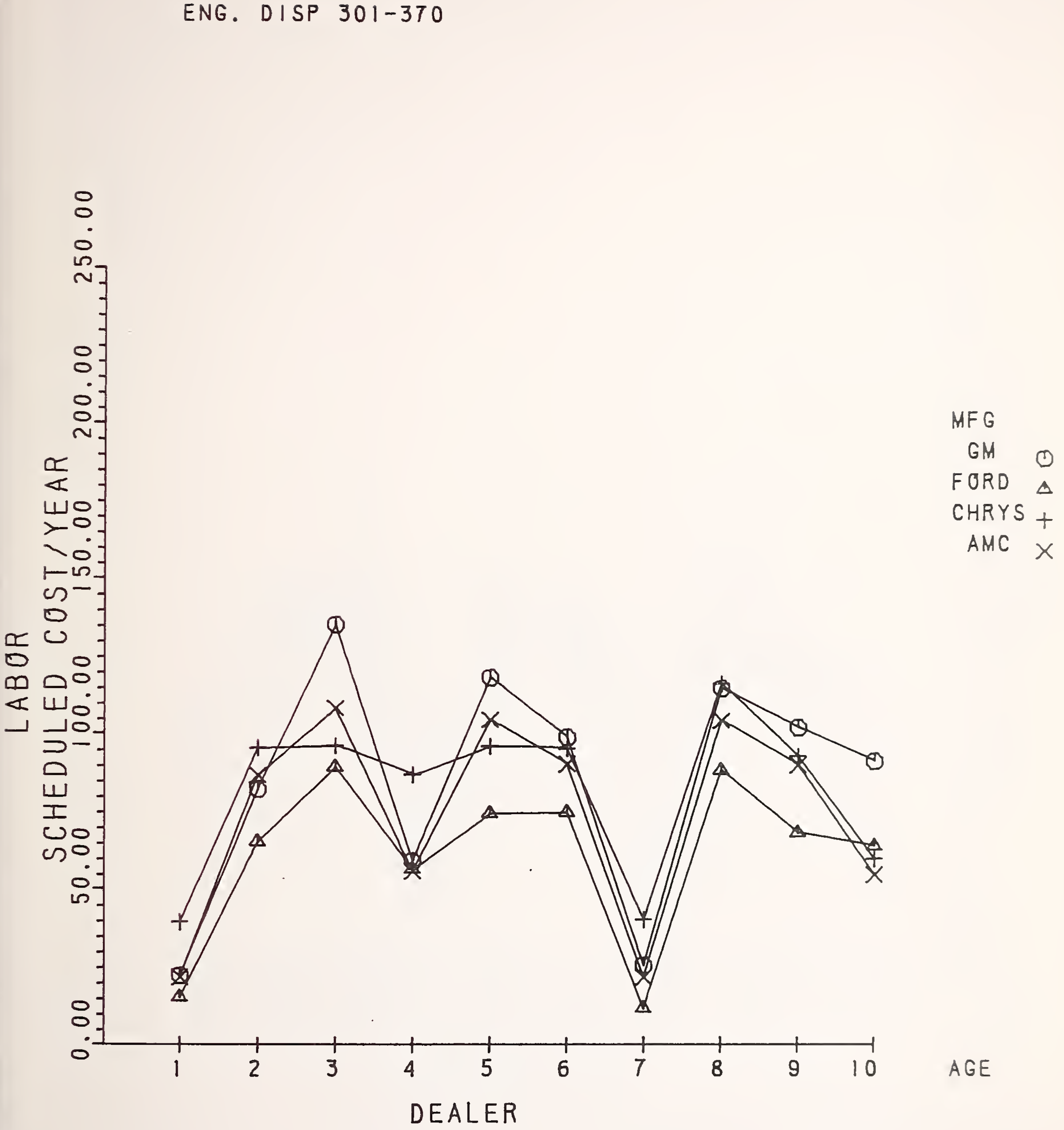

ENG. DISP 301-370
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
MFG
GM
FORD
CHRYS
AMC
1
2
3
4
5
6
7
8
9
10
AGE
DEALER

FIGURE A-96

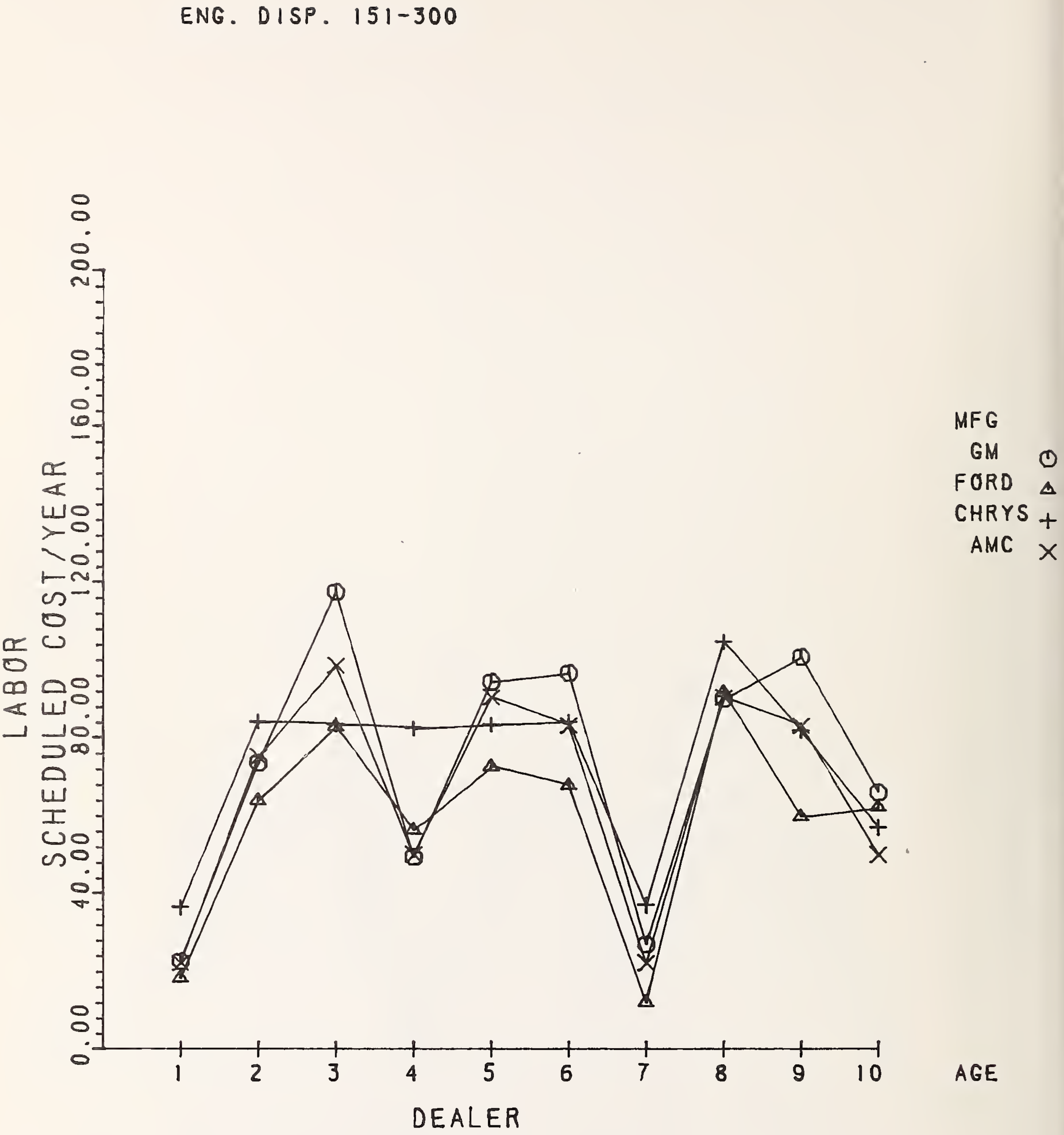

ENG. DISP. 151-300
LABOR
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM ⊖
FORD △
CHRYS +
AMC ×

FIGURE A-97

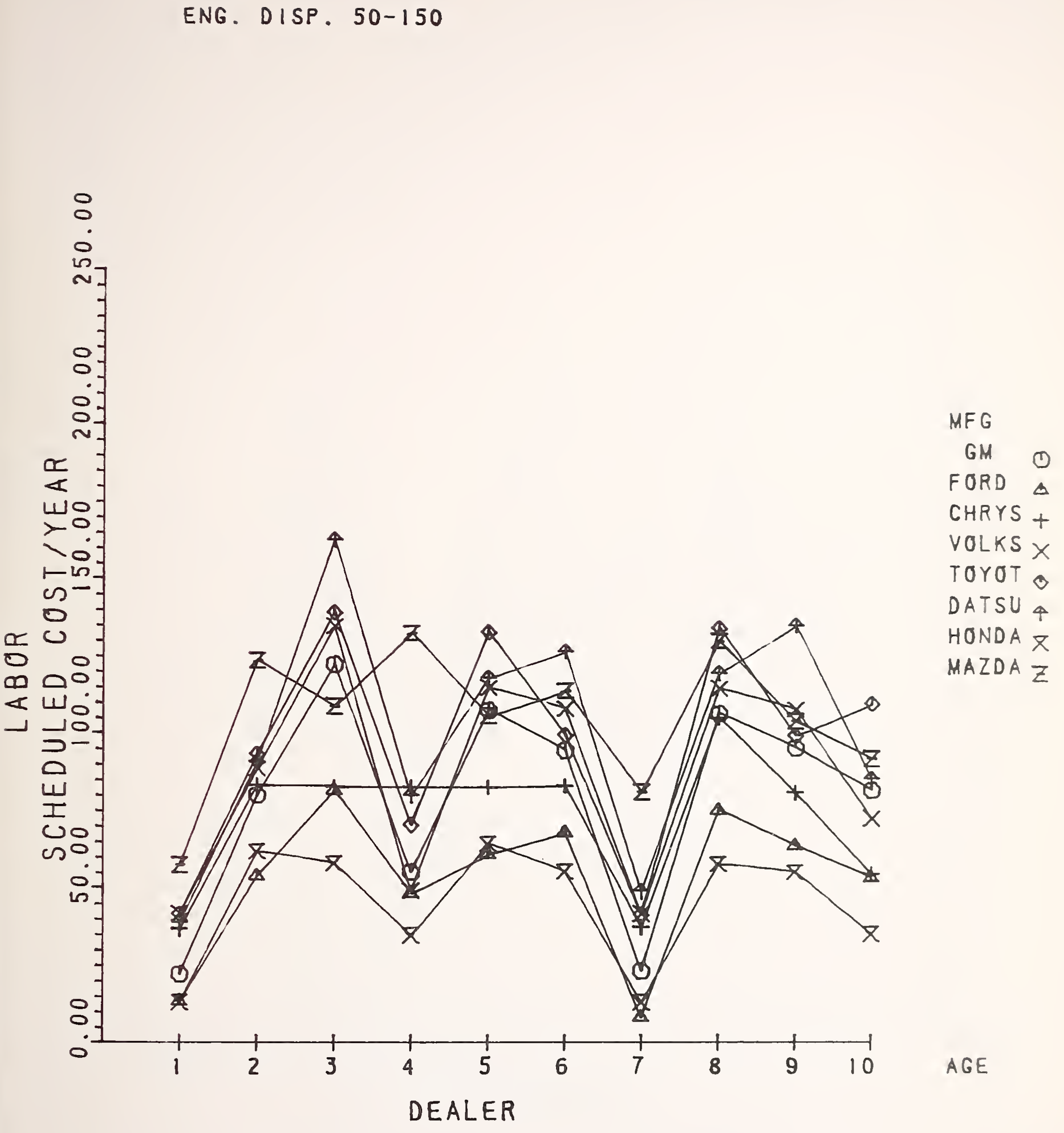

ENG. DISP. 50-150
LABOR
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
VOLKS
TOYOT
DATSU
HONDA
MAZDA

FIGURE A-98

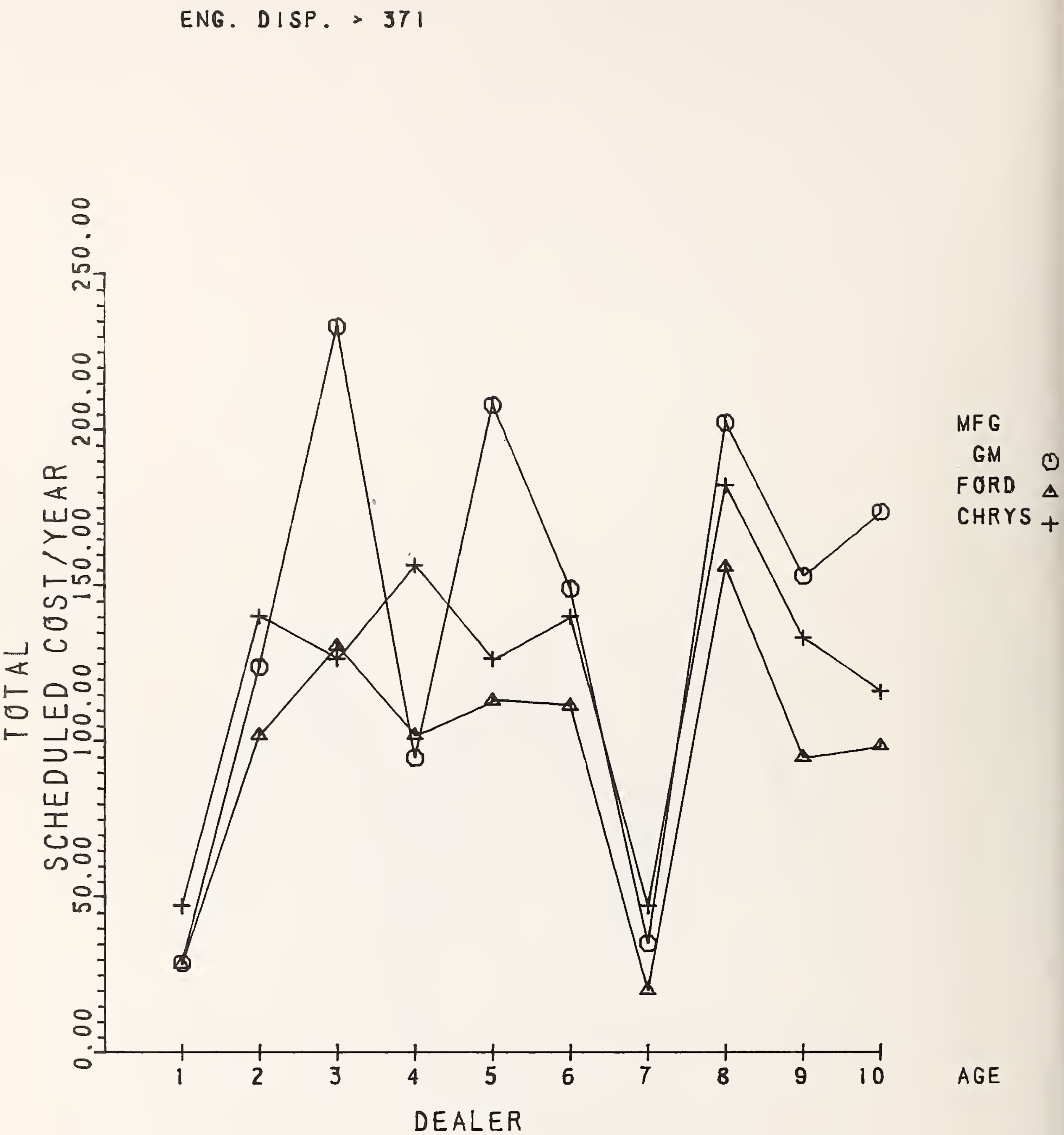

ENG. DISP. > 371
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +

FIGURE A-99

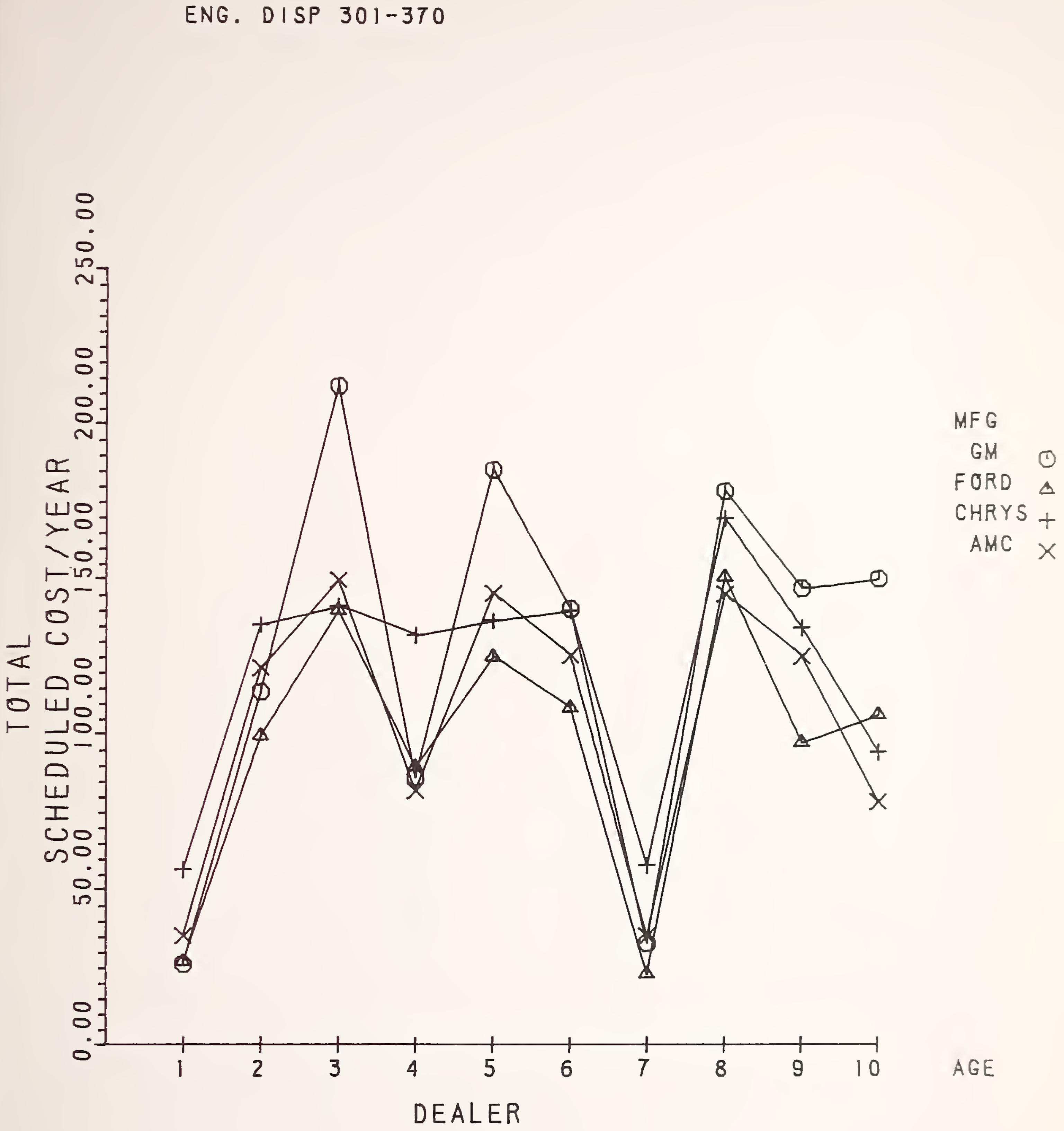

ENG. DISP 301-370
TOTAL SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM
FORD
CHRYS
AMC

FIGURE A-100

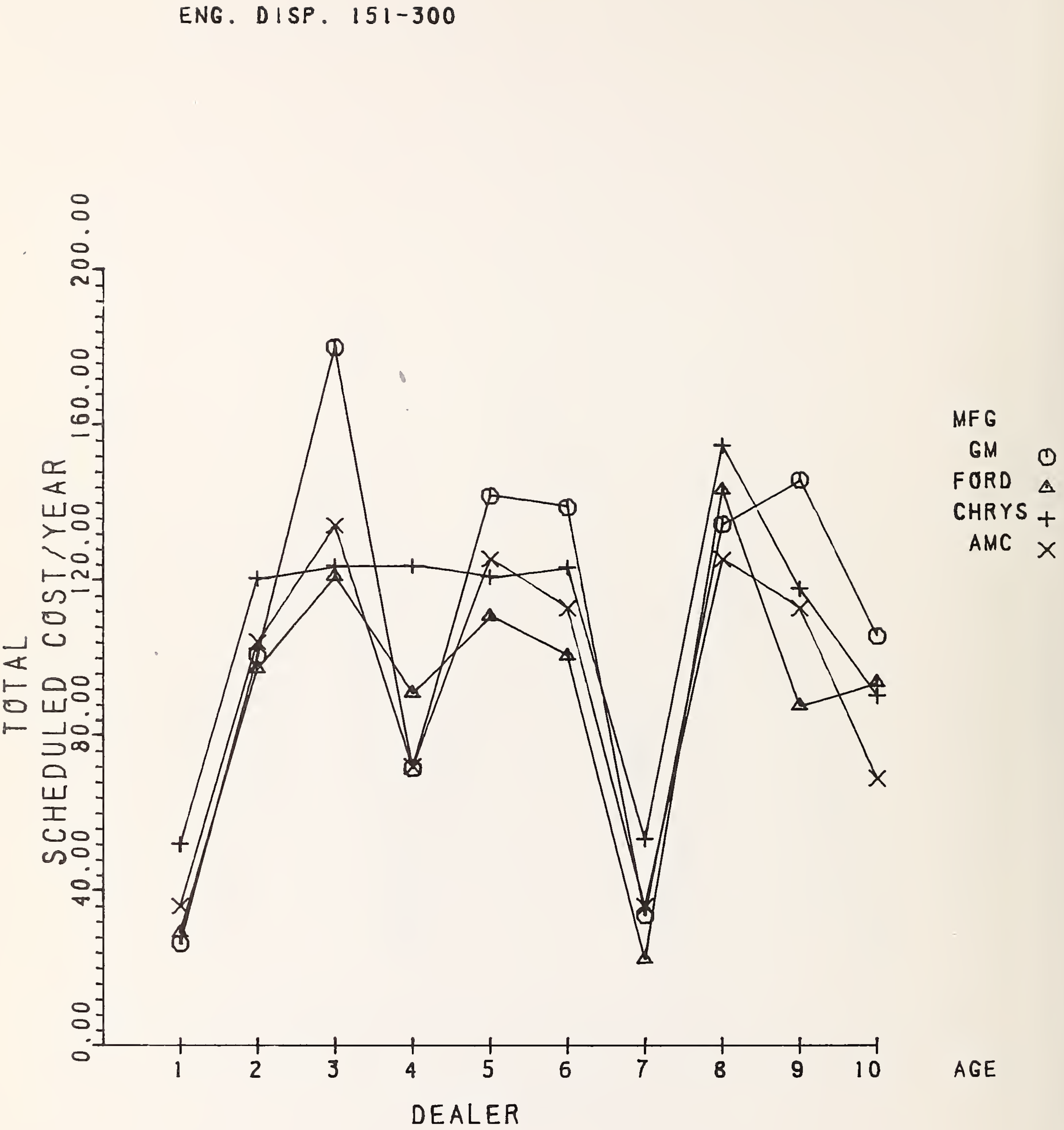

ENG. DISP. 151-300
TOTAL
SCHEDULED COST/YEAR
0.00
40.00
80.00
120.00
160.00
200.00
1
2
3
4
5
6
7
8
9
10
DEALER
AGE
MFG
GM ○
FORD △
CHRYS +
AMC ×

FIGURE A-101

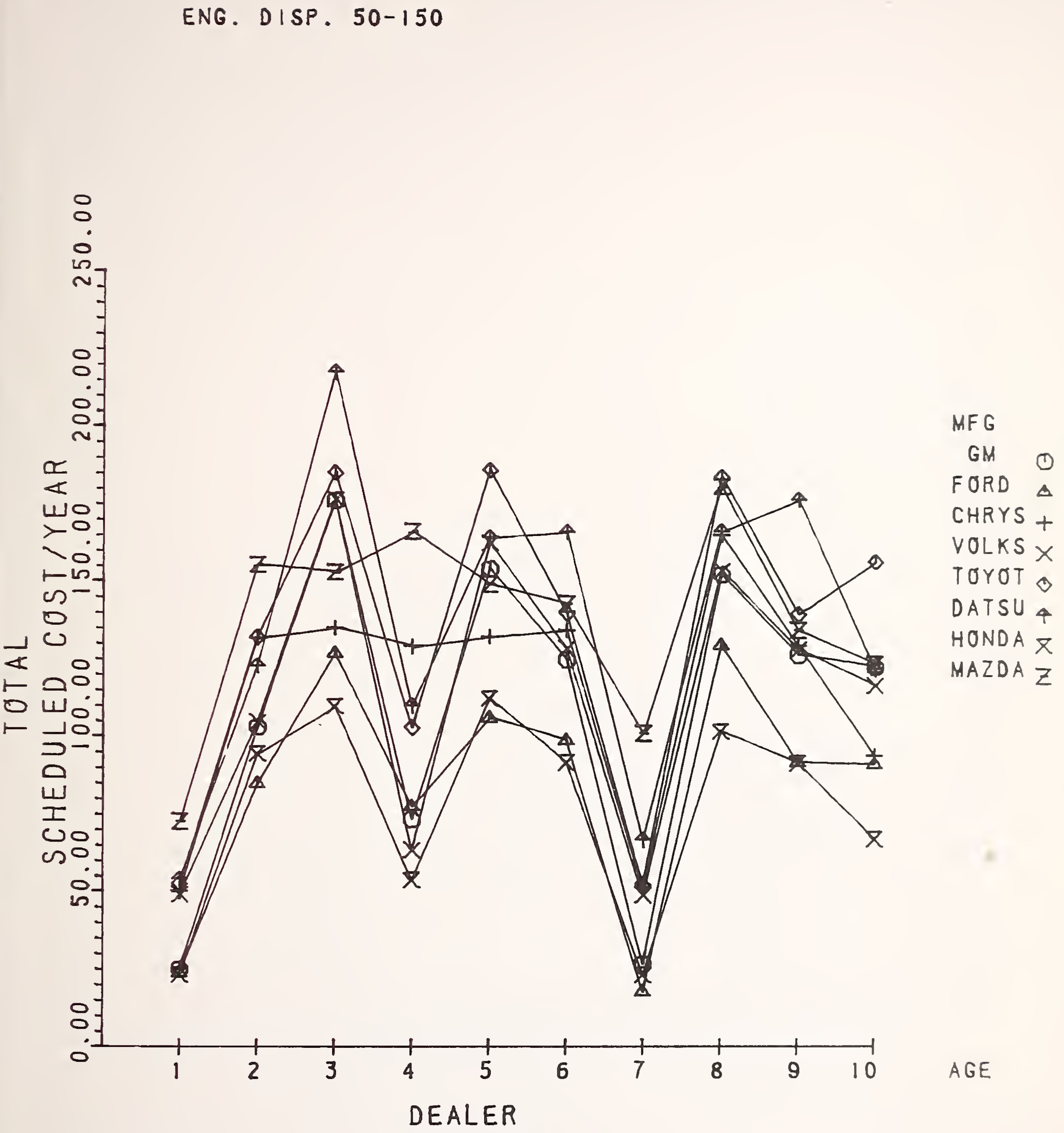

ENG. DISP. 50-150
TOTAL
SCHEDULED COST/YEAR
0.00
50.00
100.00
150.00
200.00
250.00
1
2
3
4
5
6
7
8
9
10
AGE
DEALER
MFG
GM
FORD
CHRYS
VOLKS
TOYOT
DATSU
HONDA
MAZDA

FIGURE A-102

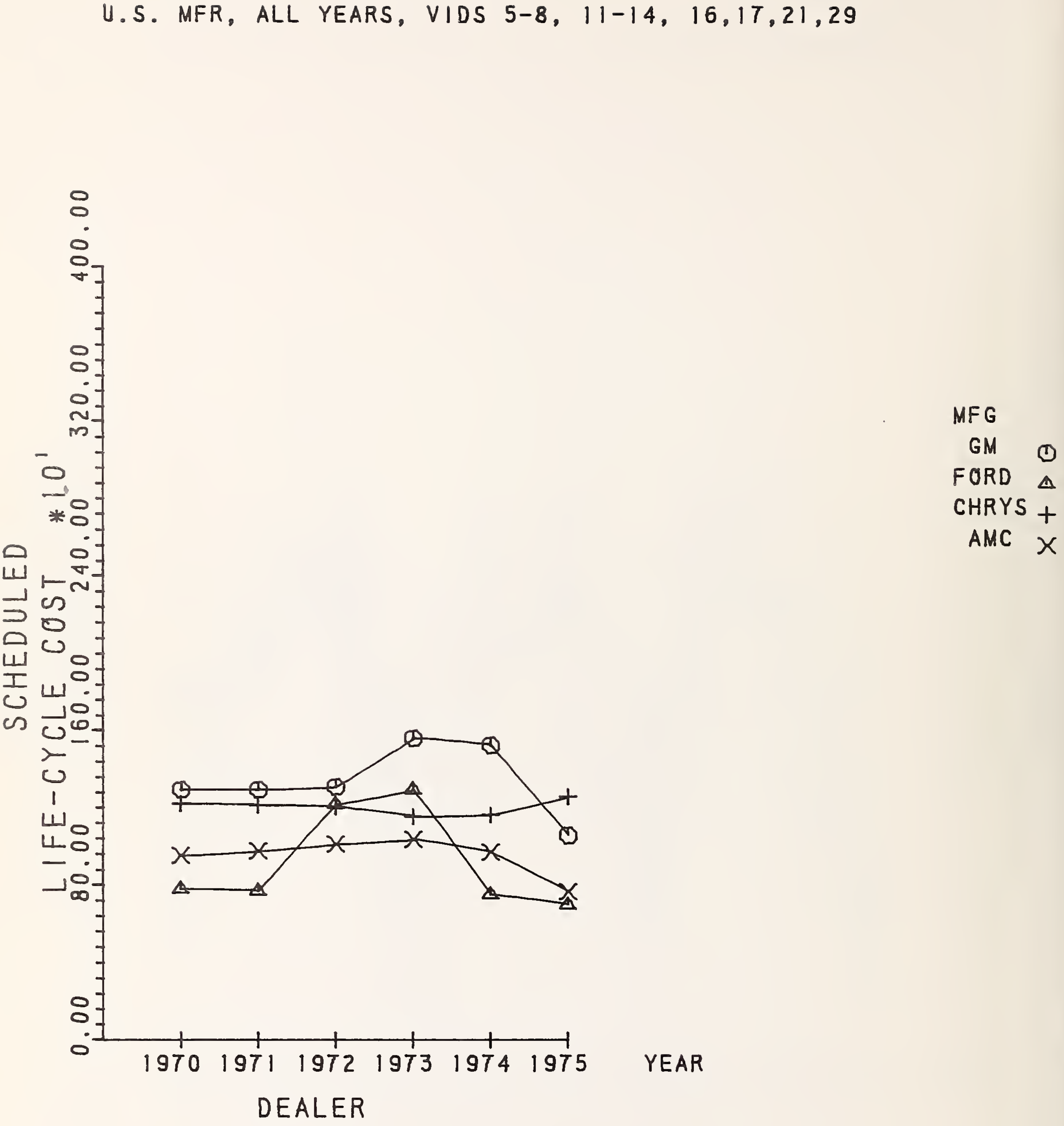

U.S. MFR, ALL YEARS, VIDS 5-8, 11-14, 16,17,21,29
SCHEDULED
LIFE-CYCLE COST *10¹
0.00
80.00
160.00
240.00
320.00
400.00
1970
1971
1972
1973
1974
1975
YEAR
DEALER
MFG
GM
FORD
CHRYS
AMC

FIGURE A-103

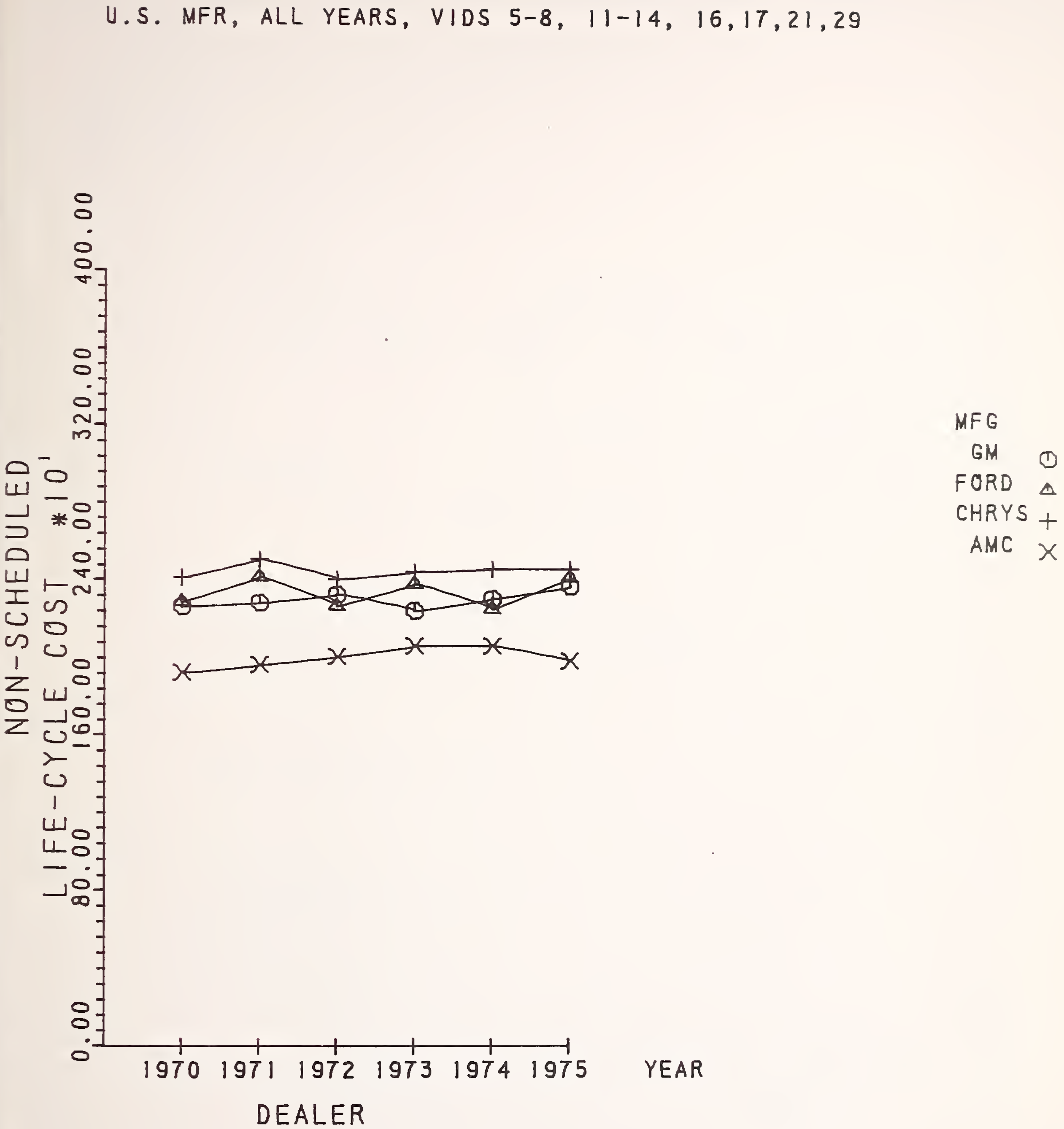

U.S. MFR, ALL YEARS, VIDS 5-8, 11-14, 16,17,21,29
NØN-SCHEDULED
LIFE-CYCLE CØST *10¹
0.00
80.00
160.00
240.00
320.00
400.00
1970
1971
1972
1973
1974
1975
YEAR
DEALER
MFG
GM
FØRD
CHRYS
AMC

FIGURE A-104

U.S. MFR, ALL YEARS, VIDS 5-8, 11-14, 16,17,21,29

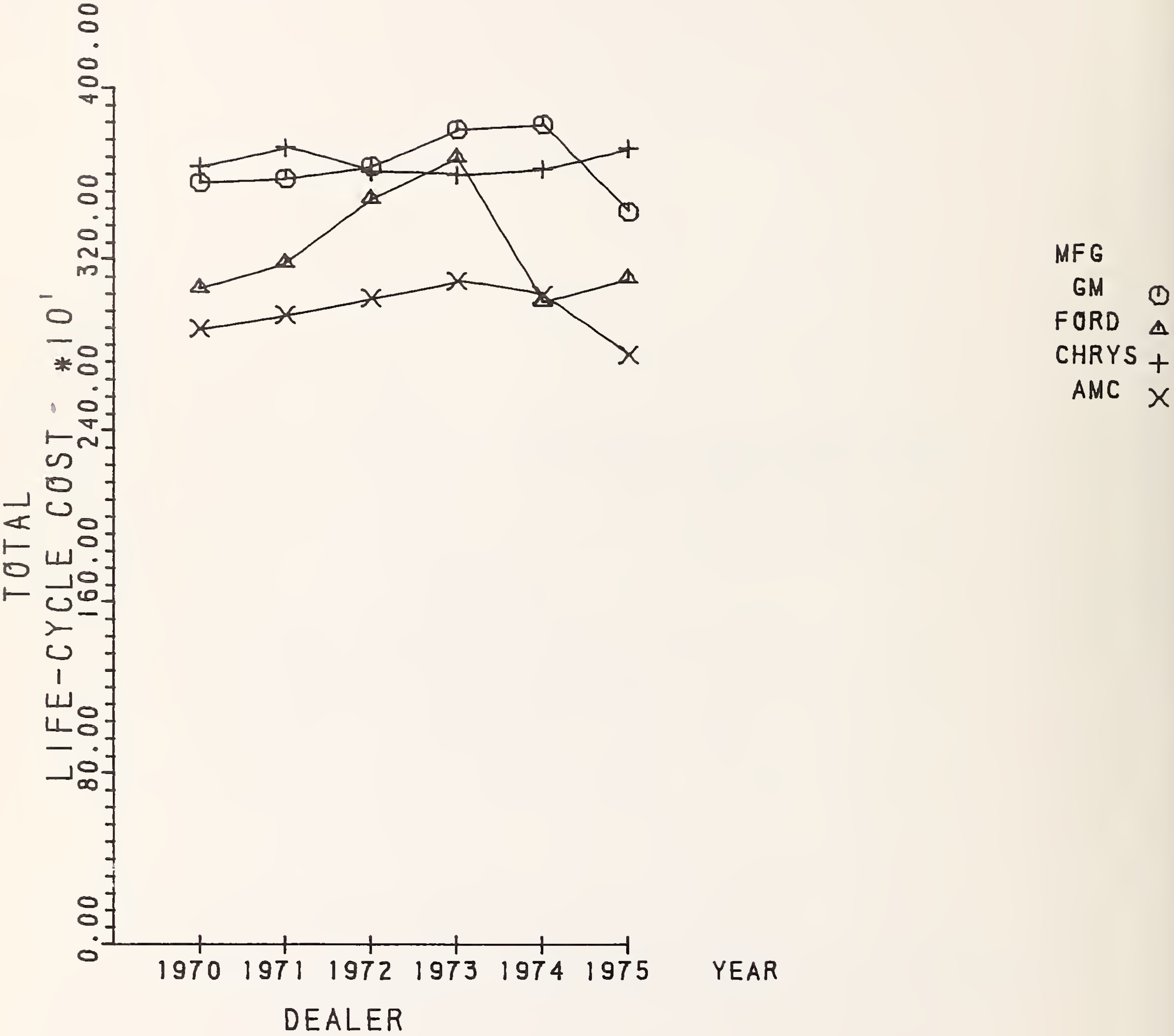


FIGURE A-105

APPENDIX B

LIST OF CARS

The key to this listing is as follows:

BODY CLASS

S = standard
I = intermediate
C = compact
SC = subcompact
L = luxury
M = minicompact
T(1) = truck under 6,000 lbs. GUW
T(2) = truck over 6,000 lbs. GUW

TRANSMISSION

A = automatic
M = manual (number in parenthesis indicates number of forward speeds if above three speeds)

ENGINE

S = this engine is standard for this car
O = this engine is an option for this car

STEERING

P = power assisted
M = not assisted (manual)

BRAKES

P = power assisted
M = not assisted (manual)
DC = disc
DM = drum

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1975

VID NO.	YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS	
5	1975	S	Chev.	Impala Bel Air	A	350	V-8 S	P	P DC	AC	4	
6	1975	S	Ford	Galaxie-Custom	A	400	V-8 O	P	P DC	AC	4	
7	1975	S	Chrys.	Newport	A	360	V-8 S	P	P DC	AC	4	
8	1975	S	Plym.	Fury/Grand Prix	A	318	V-8 S	P	P DC	AC	4	
9	1975	S	AMC	Ambassador								Discontinued
10	1975	I	Chev.	Chevelle	A	350	V-8 S	P	P DC	AC	2	
11	1975	I	Pont.	Grand Prox	A	400	V-8 S	P	P DC	AC	4	
12	1975	I	Ford	Torino	A	351	V-8 S	P	P DC	AC	4	
13	1975	I	Plym.	Satellite/Fury	A	318	V-8 S	P	P DC	AC	4	
14	1975	I	AMC	Matador	A	305	V-8 O	P	P DC	AC	4	
15	1975	C	Chev.	Nova	A	350	V-8 O	P	P DC	none	4	
16	1975	C	Chev.	Camaro	A	350	V-8 S	P	P DC	AC	2	
17	1975	C	Ford	Mustang	A	302	V-8 O	P	P DC	none	2	
18	1975	C	Ford	Maverick	A	250	L-6	P	M DM	AC	4	
19	1975	C	Dodge	Dart	A	225	L-6	P	M DC	AC	4	
21	1975	C	AMC	Hornet	A	258	L-6	P	M DM	none	4	
22	1975	C	AMC	Javelin								Discontinued
20	1975	C	Plym.	Valiant	A	225	L-6	P	M DM	none	4	
23	1975	SC	Chev.	Vega	A	140	L-4	M	M DC	none	2	
25	1975	SC	Olds.	Starfire	A	231	V-6	P	P DC	AC	2	
26	1975	SC	Ford	Pinto	A	140	L-4	M	M DC	none	2	
29	1975	SC	AMC	Gremlin	A	232	L-6	P	M DM	none	2	
24	1975	SC	Buick	Opel Manta	M-4	115.8	L-4	M	P DC	none	2	
27	1975	SC	Ford	Capri 2800	A	170.3	V-6	M	M DC	none	2	
28	1975	SC	Dodge	Colt Coupe	M	97.6	L-4	M	M DC	none	2	
30	1975	SC	VW	Rabbit	M	89.7	L-4	M	M DC	none	2	
31	1975	SC	Toyota	Corolla	M	96.9	L-4	M	M DC	none	2	
32	1975	SC	Datsun	610	M	119.1	L-4	M	M DC	none	2	
33	1975	SC	Mazda	RX3 Coupe	M	70	Rotary	M	M DC	none	2	
1	1975	L	Buick	Electra 225	A	455	V-8 S	P	P DC	AC	4	
2	1975	L	Cad.	Eldorado	A	500	V-8 S	P	P DC	AC	4	
3	1975	L	Cad.	deVille	A	500	V-8 S	P	P DC	AC	4	
4	1975	L	Lincoln	Continental	A	460	V-8 S	P	P DC	AC	4	
34	1975	M	Honda	Civic (CVCC)	M	90.8	L-4	M	M DC	none	2	
35	1975	T(1)	Chev.	C-10	M	350	V-8 2bbl.	M	M DC	none	2	
37	1975	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2	
36	1975	T(2)	Chev.	C-20	A	350	V-8 4bbl.	M	P DC	AC	2	
38	1975	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2	

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1974

YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS
1974	S	Chev.	Impala Bel Air	A	350	V-8 S	P	P DC	AC	4
1974	S	Ford	Galaxie-Custom	A	400	V-8 O	P	P DC	AC	4
1974	S	Chrys.	Newport	A	400	V-8 S	P	P DC	AC	4
1974	S	Plym.	Fury	A	400	V-8 S	P	P DC	AC	4
1974	S	AMC	Ambassador	A	360	V-8 O	P	P DC	AC	4
1974	I	Chev.	Chevelle	A	350	V-8 S	P	P DC	AC	2
1974	I	Pont.	Grand Prix	A	400	V-8 S	P	P DC	AC	4
1974	I	Ford	Torino	A	351	V-8 S	P	P DC	AC	4
1974	I	Plym.	Satellite	A	318	V-8 S	P	P DC	AC	4
1974	I	AMC	Matador	A	360	V-8 O	P	P DC	AC	4
1974	C	Chev.	Nova	A	350	V-8 S	P	M DM	none	4
1974	C	Chev.	Camaro	A	350	V-8 S	P	P DC	AC	2
1974	C	Ford	Mustang	A	140	L-4	P	M DC	none	2
1974	C	Ford	Maverick	A	200	L-6	P	M DM	none	4
1974	C	Dodge	Dart	A	198	L-6	P	M DM	none	4
1974	C	Plym.	Valiant	A	198	L-6	P	M DM	none	4
1974	C	AMC	Hornet	A	232	L-6	P	M DM	none	4
1974	C	AMC	Javelin	A	360	V-8 O	P	P DC	none	2
1974	SC	Chev.	Vega	A	140	L-4	M	M DC	none	2
1974	SC	Ford	Pinto	A	122	L-4	M	M DC	none	2
1974	SC	AMC	Gremlin	A	232	L-6	M	M DM	none	2
1974	SC	Buick	Opel Manta	M	115.8	L-4	M	M DC	none	2
1974	SC	Ford	Capri 2800	A	170	V-6	M	M DC	none	2
1974	SC	Dodge	Colt Coupe	M	97.5	L-4	M	M DC	none	2
1974	SC	VW	Beetle	M	96.7	H-4	M	M DC	none	2
1974	SC	Toyota	Corolla 1600	M	96.9	L-4	M	M DC	none	2
1974	SC	Datsun	610	M	119	L-4	M	M DC	none	2
1974	SC	Mazda	RX3 Coupe	M	70	Rotary	M	M DC	none	2
1974	L	Buick	Electra 225	A	455	V-8 S	P	P DC	AC	4
1974	L	Cad.	Eldorado	A	500	V-8 S	P	P DC	AC	4
1974	L	Cad.	de Ville	A	472	V-8 S	P	P DC	AC	4
1974	L	Lincoln	Continental	A	460	V-8 S	P	P DC	AC	4
1974	M	Honda	Civic	M	71.3	L-4	M	M DC	none	2
1974	T(1)	Chev.	C-10	M	350	V-8 2bbl	M	M DC	none	2
1974	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2
1974	T(2)	Chev.	C-20	A	350	V-8 4bbl	M	P DC	AC	2
1974	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1973

YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS
1973	S	Chev.	Impala Bel Air	A	350	V-8 S	P	P DC	AC	4
1973	S	Ford	Galaxie-Custom	A	400	V-8 O	P	P DC	AC	4
1973	S	Chrys.	Newport	A	400	V-8 S	P	P DC	AC	4
1973	S	Plym.	Fury	A	360	V-8 O	P	P DC	AC	4
1973	S	AMC	Ambassador	A	360	V-8 O	P	P DC	AC	4
1973	I	Chev.	Chevelle	A	350	V-8 O	P	P DC	AC	2
1973	I	Pont.	Grand Prix	A	400	V-8 S	P	P DC	AC	4
1973	I	Ford	Torino	A	302	V-8 S	P	P DC	AC	4
1973	I	Plym.	Satellite	A	318	V-8 S	P	P DC	AC	4
1973	I	AMC	Matador	A	360	V-8 O	P	M DM	AC	4
1973	C	Chev.	Nova	A	307	V-8 S	P	M DM	none	4
1973	C	Chev.	Camaro	A	350	V-8 O	P	P DC	AC	2
1973	C	Ford	Mustang	A	351	V-8 O	P	P DC	AC	2
1973	C	Ford	Maverick	A	200	L-6	P	M DM	none	4
1973	C	Dodge	Dart	A	198	L-6	P	M DM	none	4
1973	C	Plym.	Valiant	A	198	L-6	P	M DM	none	4
1973	C	AMC	Hornet	A	232	L-6	P	M DM	none	4
1973	C	AMC	Javelin	A	360	V-8 O	P	M DM	none	2
1973	SC	Chev.	Vega	A	140	L-4	M	M DC	none	2
1973	SC	Ford	Pinto	A	97.6	L-4	M	M DC	none	2
1973	SC	AMC	Gremlin	A	232	L-6	M	M DM	none	2
1973	SC	Buick	Opel Manta	M	115.8	L-4	M	M DC	none	2
1973	SC	Ford	Capri 2600	A	155	V-6	M	M DC	none	2
1973	SC	Dodge	Colt HT	M	97.5	L-4	M	M DC	none	2
1973	SC	VW	Beetle	M	96.7	H-4	M	M DM	none	2
1973	SC	Toyota	Corolla 1600	M	96.9	L-4	M	M DC	none	2
1973	SC	Datsun	PL 610	M	108	L-4	M	M DM	none	2
1973	SC	Mazda	RX 3 Coupe	M	70	Rotary	M	M DM	none	2
1973	L	Buick	Electra 225	A	455	V-8 S	P	P DC	AC	4
1973	L	Cad.	Eldorado	A	500	V-8 S	P	P DC	AC	4
1973	L	Cad.	de Ville	A	472	V-8 S	P	P DC	AC	4
1973	L	Lincoln	Continental	A	460	V-8 S	P	P DC	AC	4
1973	M	Honda	Civic	M	71.3	L-4	M	M DC	none	2
1973	T(1)	Chev.	C-10	M	350	V-8 2bbl	M	M DC	none	2
1973	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2
1973	T(2)	Chev.	C-20	A	350	V-8 4bbl	M	P DC	AC	2
1973	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1972

YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS	
1972	S	Chev.	Impala Bel Air	A	350	V-8 S	P	P DC	AC	4	
1972	S	Ford	Galaxia	A	351	V-8 S	P	P DC	AC	4	
1972	S	Chrys.	Newport	A	360	V-8 S	P	P DC	AC	4	
1972	S	Plym.	Fury	A	360	V-8 O	P	P DC	AC	4	
1972	S	AMC	Ambassador	A	304	V-8 S	P	P DM	AC	4	
1972	I	Chev.	Chevelle	A	350	V-8 O	P	P DM	AC	2	
1972	I	Pont.	Grand Prix	A	400	V-8 S	P	P DC	AC	4	
1972	I	Ford	Torino	A	351	V-8 O	P	P DC	AC	4	
1972	I	Plym.	Satellite	A	318	V-8 S	P	P DC	AC	4	
1972	I	AMC	Matador	A	360	V-8 O	P	M DM	none	4	
1972	C	Chev.	Nova	A	250	L-6	P	M DM	none	4	
1972	C	Chev.	Camaro	A	350	V-8 O	P	M DC	none	2	
1972	C	Ford	Mustang	A	351	V-8 O	P	P DC	none	2	
1972	C	Ford	Maverick	A	170	L-6	P	M DM	none	4	
1972	C	Dodge	Dart	A	198	L-6	P	M DM	none	4	
1972	C	Plym.	Valiant	A	198	L-6	P	M DM	none	4	
1972	C	AMC	Hornet	A	232	L-6	P	M DM	none	4	
1972	C	AMC	Javelin	A	360	V-8 O	P	M DM	AC	2	
1972	SC	Chev.	Vega 2300	M	140	L-4	M	M DC	none	2	
1972	SC	Ford	Pinto	A	97.6	L-4	M	M DC	none	2	
1972	SC	AMC	Gremlin	A	232	L-6	M	M DM	none	2	
1972	SC	Buick	Opel Manta 1900 Sport Coupe	M	115.8	L-4	M	M DC	none	2	
1972	SC	Ford	Capri 2000	M	122	L-4	M	P DC	none	2	
1972	SC	Dodge	Colt HT	A	97.5	L-4	M	M DC	none	2	
1972	SC	VW	Beetle	M	96.7	H-4	M	M DM	none	2	
1972	SC	Toyota	Corolla 1600	M	96.9	L-4	M	M DC	none	2	
1972	SC	Datsun	PL 510	M	97.3	L-4	M	M DC	none	2	
1972	SC	Mazda	RX2 Coupe	M	70	Rotary	M	M DM	none	2	
1972	L	Buick	Electra 225	A	455	V-8 S	P	P DC	AC	4	
1972	L	Cad.	Eldorado	A	500	V-8 S	P	P DC	AC	4	
1972	L	Cad.	de Ville	A	472	V-8 S	P	P DC	AC	4	
1972	L	Lincoln	Continental	A	460	V-8 S	P	P DC	AC	4	
1972	M	Honda									not imported in suff. quantity
1972	T(1)	Chev.	C-10	M	350	V-8 2bbl	M	M DC	none	2	
1972	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2	
1972	T(2)	Chev.	C-20	A	350	V-8 4bbl	M	P DC	AC	2	
1972	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2	

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1971

YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS
1971	S	Chev.	Impala Bel Air	A	350	V-8 S	P	M DC	AC	4
1971	S	Ford	Galaxie	A	351	V-8 S	P	M DC	AC	4
1971	S	Chrys.	Newport	A	360	V-8 S	P	M DC	AC	4
1971	S	Plym.	Fury	A	360	V-8 O	P	M DC	AC	4
1971	S	AMC	Ambassador	A	304	V-8 S	P	P DM	AC	4
1971	I	Chev.	Chevelle	A	307	V-8 S	P	M DM	AC	2
1971	I	Pont.	Grand Prix	A	400	V-8 S	P	M DC	AC	4
1971	I	Ford	Torino	A	351	V-8 O	P	M DM	AC	4
1971	I	Plym.	Satellite	A	318	V-8 S	P	M DM	AC	4
1971	I	AMC	Matador	A	360	V-8 O	P	M DM	none	4
1971	C	Chev.	Nova	A	250	L-6	P	M DM	none	4
1971	C	Chev.	Camaro	A	307	V-8 S	P	M DM	none	2
1971	C	Ford	Mustang	A	351	V-8 O	P	M DM	none	2
1971	C	Ford	Maverick	A	170	L-6	M	M DM	none	4
1971	C	Dodge	Dart	A	198	L-6	P	M DM	none	4
1971	C	Plym.	Valiant	A	198	L-6	P	M DM	none	4
1971	C	AMC	Hornet	A	232	L-6	M	M DM	none	4
1971	C	AMC	Javelin	A	360	V-8 O	P	M DM	none	2
1971	SC	Chev.	Vega	M	140	L-4	M	M DC	none	2
1971	SC	Ford	Pinto	M	97.6	L-4	M	M DM	none	2
1971	SC	AMC	Gremlin	M	232	L-6	M	M DM	none	2
1971	SC	Buick	Opel 1900 Sports Coupe	M	115.8	L-4	M	M DC	none	2
1971	SC	Ford	Capri 1600	M	97.6	L-4	M	M DC	none	2
1971	SC	Dodge	Colt HT	A	97.5	L-4	M	M DM	none	2
1971	SC	VW	Beetle	M	96.7	H-4	M	M DM	none	2
1971	SC	Toyota	Corolla 1600	M	96.9	L-4	M	M DC	none	2
1971	SC	Datsun	PL 510	M	97.3	L-4	M	M DC	none	2
1971	SC	Mazda	R-100 Coupe	M	70	Rotary	M	M DC	none	2
1971	L	Buick	Electra 225	A	455	V-8 S	P	M DC	AC	4
1971	L	Cad.	Eldorado	A	500	V-8 S	P	M DC	AC	4
1971	L	Cad.	de Ville	A	472	V-8 S	P	M DC	AC	4
1971	L	Lincoln	Continental	A	460	V-8 S	P	M DC	AC	4
1971	T(1)	Chev.	C-10	M	350	V-8 2bbl	M	M DC	none	2
1971	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2
1971	T(2)	Chev.	C-20	A	350	V-8 4bbl	M	P DC	AC	2
1971	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2

MOTOR VEHICLE CLASSIFICATION BY BODY SIZE, 1970

YEAR	BODY CLASS	MAKE	MODEL	TRANS.	CID	ENGINE	STEERING	BRAKES	AIR COND.	DOORS	
1970	S	Chev.	Impala Bel Air	A	350	V-8 S	P	M DC	AC	4	
1970	S	Ford	Galaxie	A	351	V-8 S	P	M DC	AC	4	
1970	S	Chrys.	Newport	A	383	V-8 S	P	P DM	AC	4	
1970	S	Plym.	Fury	A	318	V-8 S	P	P DM	AC	4	
1970	S	AMC	Ambassador	A	304	V-8 S	P	P DM	AC	4	
1970	I	Chev.	Chevelle	A	350	V-8 O	P	M DM	none	2	
1970	I	Pont.	Grand Prix	A	400	V-8 S	P	M DC	AC	4	
1970	I	Ford	Torino (Fairlane)	A	351	V-8 O	P	M DM	none	4	
1970	I	Plym.	Belvedere	A	318	V-8 S	P	M DM	none	4	Satellite not in production
1970	I	AMC	Matador								not in productior
1970	C	Chev.	Nova	A	230	L-6	P	M DM	none	4	
1970	C	Chev.	Camaro	A	307	V-8 S	P	M DM & M DC	none	2	(1970) (1970 1/2)
1970	C	Ford	Mustang	A	351	V-8 O	P	M DM	none	2	
1970	C	Ford	Maverick	A	170	L-6	M	M DM	none	4	
1970	C	Dodge	Dart	A	198	L-6	P	M DM	none	4	
1970	C	Plym.	Valiant	A	198	L-6	M	M DM	none	4	
1970	C	AMC	Hornet	A	199	L-6	M	M DM	none	4	
1970	C	AMC	Javelin	A	360	V-8 O	P	M DM	none	2	
1970	SC	Chev.	Vega								not in production
1970	SC	Ford	Pinto								not in production
1970	SC	AMC	Gremlin	M	199	L-6	M	M DM	none	2	
1970	SC	Buick	Opel Manta	M	65.8	L-4	M	M DC	none	2	
1970	SC	Ford	Capri								not available
1970	SC	Dodge	Colt								not available
1970	SC	VW	Beetle	M	96.7	H-4	M	M DM	none	2	
1970	SC	Toyota	Corolla	M	71.1	L-4	M	M DM	none	2	
1970	SC	Datsun	PL 510	M	97.3	L-4	M	M DC	none	2	
1970	SC	Mazda									not available
1970	L	Buick	Electra 225	A	455	V-8 S	P	M DC	AC	4	
1970	L	Cad.	Eldorado	A	500	V-8 S	P	M DC	AC	4	
1970	L	Cad.	de Ville	A	472	V-8 S	P	M DC	AC	4	
1970	L	Lincoln	Continental	A	460	V-8 S	P	M DC	AC	4	
1970	T(1)	Chev.	C-10	M	350	V-8 2bbl	M	M DC	none	2	
1970	T(1)	Ford	F-100	M	300	L-6	M	M DC	none	2	
1970	T(2)	Chev.	C-20	A	350	V-8 4bbl	M	P DC	AC	2	
1970	T(2)	Ford	F-250	A	360	V-8	M	P DC	AC	2	

APPENDIX C

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND VEHICLE SIZE

L = Luxury

VID	YEAR					
1	75	74	73	72	71	70
2	75	74	73	72	71	70
3	75	74	73	72	71	70
4	75	74	73	72	71	70

SC = Subcompact

VID	YEAR					
23	75	74	73	72	71	-
24	75	74	73	72	71	70
25	75	-	-	-	-	-
26	75	74	73	72	71	-
27	75	74	73	72	71	-
28	75	74	73	72	71	-
29	75	74	73	72	71	70
30	75	-	-	-	-	-
31	75	74	73	72	71	70
32	75	74	73	72	71	70
33	-	-	-	-	-	-

T = Trucks

VID	YEAR					
35	75	74	73	72	71	70
36	75	74	73	72	71	70
37	75	74	73	72	71	70
38	75	74	73	72	71	70

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND VEHICLE SIZE (CONT.)

Standard

VID	YEAR					
5	75	74	73	72	71	70
6	75	74	73	72	71	70
7	75	74	73	72	71	70
8	75	74	73	72	71	70
9	75	74	73	72	71	70

Intermediate

VID	YEAR					
10	75	74	73	72	71	70
11	75	74	73	72	71	70
12	75	74	73	72	71	70
13	75	74	73	72	71	70
14	75	74	73	72	71	70

Compact

VID	YEAR					
15	75	74	73	72	71	70
16	75	74	73	72	71	70
17	75	74	73	72	71	70
18	75	74	73	72	71	70
19	75	74	73	72	71	70
20	75	74	73	72	71	70
21	75	74	73	72	71	70
22	75	74	73	72	71	70

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND VEHICLE WEIGHT

OVER 4,000 POUNDS

VID	YEAR					
5	75	74	73	72	71	70
6	75	74	73	72	71	-
7	75	74	73	72	71	70
8	75	74	73	72	71	-
10	-	74	-	-	-	-
11	75	74	73	72	71	-
12	-	74	-	-	-	-
13	-	-	-	72	-	-
1	75	74	73	72	71	70
2	75	74	73	72	71	70
3	75	74	73	72	71	70
4	75	74	73	72	71	70

3600 - 4000

6	-	-	-	-	-	70
8	-	-	-	-	-	70
9	-	74	73	72	71	70
10	75	-	73	72	-	-
11	-	-	-	-	-	70
12	-	-	73	72	71	-
13	75	74	73	-	-	-
14	75	74	73	-	-	-
15	75	-	-	-	-	-
16	75	74	-	-	-	-
17	-	-	73	-	-	-
22	-	--	-	-	-	70

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND VEHICLE WEIGHT CONT.

3201 - 3600

VID	YEAR					
10	-	-	-	-	71	70
12	-	-	-	-	-	70
13	-	-	-	-	71	70
14	-	-	-	72	71	-
15	-	74	73	72	-	-
16	-	-	73	72	71	70
17	-	-	-	72	71	70
18	75	-	-	-	-	-
19	75	-	-	-	-	-
22	-	74	73	72	71	-

2601 - 3200

15	-	-	-	72	71	70
17	75	74	-	-	-	-
18	-	74	73	72	71	70
19	-	74	73	72	71	70
20	75	74	73	72	71	70
21	75	74	73	72	71	70
25	75	-	-	-	-	-
27	75	74	-	-	-	-
29	75	74	73	72	71	70

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND VEHICLE WEIGHT CONT.

1500 - 2600

VID	YEAR					
23	75	74	73	72	71	-
24	75	74	73	72	71	70
26	75	74	73	72	71	-
27	-	-	73	72	71	-
28	75	74	73	72	71	-
30	-	74	73	72	71	70
31	75	74	73	72	71	70
32	75	74	73	72	71	70
34	75	74	73	-	-	-

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND ENGINE DISPLACEMENT

$>$371 CID

VID	YEAR					
1	75	74	73	72	71	70
2	75	74	73	72	71	70
3	75	74	73	72	71	70
4	75	74	73	72	71	70
6	75	74	73	-	-	-
7	-	74	73	-	-	-
8	-	74	-	-	-	-
11	75	74	73	72	71	70

301 - 370

5	75	74	73	72	71	70
6	-	-	-	72	71	70
7	75	-	-	72	71	70
8	75	-	73	72	71	70
9	-	74	73	72	71	70
10	75	74	73	72	71	70
12	75	74	73	72	71	70
13	75	74	73	72	71	70
14	75	74	73	72	71	-
15	75	74	73	-	-	-
16	75	74	73	72	71	70
17	75	-	73	72	71	70
22	-	74	73	72	71	70

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND ENGINE DISPLACEMENT CONT.

151 - 300

VID	YEAR					
15	-	-	-	72	71	70
17	-	74	-	-	-	-
18	75	74	73	72	71	70
19	75	74	73	72	71	70
20	75	74	73	72	71	70
21	75	74	73	72	71	70
27	75	74	73	-	-	-
29	75	74	73	72	71	70
25	75	-	-	-	-	-

<150 CID

23	75	74	73	72	71	-
24	75	74	73	72	71	70
26	75	74	73	72	71	-
27	-	-	-	72	71	-
28	75	74	73	72	71	-
30	75	74	73	72	71	70
31	75	74	73	72	71	70
32	75	74	73	72	71	70
34	75	74	73	-	-	-

LISTS OF VEHICLE IDENTIFICATION NUMBERS INCLUDED IN EACH PARAMETRIC ANALYSIS

GRAPHS OF SCHEDULED, UNSCHEDULED, AND TOTAL COSTS BY MANUFACTURER AND YEAR OF MFR.

GM	FORD	CHRYSLER	AMC
5	6	7	14
11	12	8	21
16	17	13	29

APPENDIX D

REPORT OF NEW TECHNOLOGY

Although no inventions or discoveries were made, improvements were made. For example, an improved detailed parametric analysis was made to determine the influence of vehicle characteristics on life cycle maintenance costs. The summary of this study is shown on Tables 3-2 and 3-7 and is discussed, in detail, in Sections 3.1 through 3.5. Also, an improved methodology was developed for the assessment of vehicle component durability of new designs. This assessment methodology may be used to evaluate the practicality of new materials, designs, and/or technologies. The improved methodology is described in Section 5.

N. Paulhus

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