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AN INVESTIGATION OF DESIGN, MAINTENANCE AND OPERATING PROCEDURES OF WHEELCHAIR LIFTS ON TRANSIT BUSES: PHASE I REPORT MARCH 1991

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SUMMARY:

There is a concern today that wheelchair lifts installed in transit buses are found occasionally to be inoperative. While the exact nature of the problems related to these lifts is not documented in the literature, it is generally felt that these problems are not the consequence of a single factor. Rather, these are caused by a combination of factors encompassing the design, manufacturing, operation and maintenance of these lifts.

A project is currently being conducted at the Department of Civil Engineering, Wayne State University to investigate the design, operation and maintenance aspects of wheelchair lifts. The objective of this project is to both assess the nature of the problems pertaining to any one or more of the combination of the design, manufacturing, operation, maintenance of wheelchair lifts of transit buses and to propose upgrade needs or operational changes to alleviate the service problems associated with the wheelchair lifts. The project is to be conducted in three phases over a three year period (1989-92). This report covers the work completed in the first year. The approach taken to attain the study objectives can be briefly described as a series of sequential steps as follows:

Step 1 - Operator Survey: A number of transit operators (mostly non-urban operators) were interviewed for their input to the problem identification process. For this purpose, a comprehensive questionnair survey was prepared addressing issues of design, manufacturing, maintenance, and operation of wheelchair lifts. The survey was conducted on site with personal visits to transit operator offices.

Step 2 - Compiling Technical Information: Through a formal library search process, a variety of technical information on wheelchair lifts was compiled. Much of the technical data thus compiled was used in the understanding of the behavior of the structural components and in the development of a finite element model.

Step 3 - Manufacturer Survey: A limited survey among the major wheelchair lift manufacturers in the U.S. was conducted. The survey was originally intended to be used to review the process of design and manufacturing of wheelchair lifts and their conformance to federal standards. Other objectives of this survey were to assess the manufacturer's perception on the probable causes of lift failure and to determine the possible impact of emerging technologies on the design and manufacturing process of these lifts. Unfortunately the survey results were of little consequence to the project because of a poor response.

Step 4 - Engineering Analysis of Structural/Mechanical Components: The purpose of this task was to identify specific operating components of the wheelchair lifts where failure/malfunctioning is likely to occur. The structural, mechanical and sensing components of the lift were analyzed. Also a computer based finite element model was developed to analyze the structural components of the lift mechanism. Further refinements to the model are being conducted in Phase-2.

Step 5 - Analysis of Repair Data: Available data on maintenance/repair of wheelchair lifts was collected from two operating agencies in Southeast Michigan. The data thus collected was analyzed to discern possible patterns in the maintenance needs of the wheelchair lifts. Also, the framework of a reliability model was established using available repair data on wheelchair lifts. In Phase-II, currently underway, the modelling work (both structural and reliability) has been continued in an effort to refine the models and calibrate the various model parameters. Also an experimental investigation of the operation of wheelchair lifts will be initiated to aid in the development of structural specifications to improve the operations of wheelchair lifts. Completion of the necessary experimental testing is expected during the Phase-III of the project in 1992.

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1. INTRODUCTION:

1.1 Overview:

Wheelchair lifts used in public transportation buses are categorized with respect to their architecture as: active lifts (platform lifts), and passive lifts (folding lifts). The terminologies are adopted from the USDOT Publication UMTA-IT06-0322-87 "National Workshop on Bus-Wheelchair Accessibility - Guideline Specifications for Lifts" [7]. The USDOT-UMTA publication defines active and passive lifts as follows:

> Active Lift: An active lift is one that when stowed may interfere with the use of the vehicle entrance where the lift is located and that when being raised and lowered operates primarily outside the body of the vehicle. (Figure 1)
>
> Passive Lift: A passive lift is one that when stowed allows the unlimited use of the vehicle door in which the lift is located. (Figure 2)

For the purpose of this document, the term, "platform lift" has been used instead of active lift and "folding lift" designates passive lift. In addition, following the definition of automatic lifts, if a platform lift is lowered by power rather than gravity, the lift is designated automatic.

A set of guidelines developed in 1986 for wheelchair lifts and other securement devices in the aforementioned UMTA document states that passive wheelchair lifts are primarily used on transit buses and the active ones are mostly used for para-transit vehicles, smaller buses and ramps. In addition, the manual also defines the terms lifts and automatic lift (or wheelchair lift) with direct relevance to this project as follows:

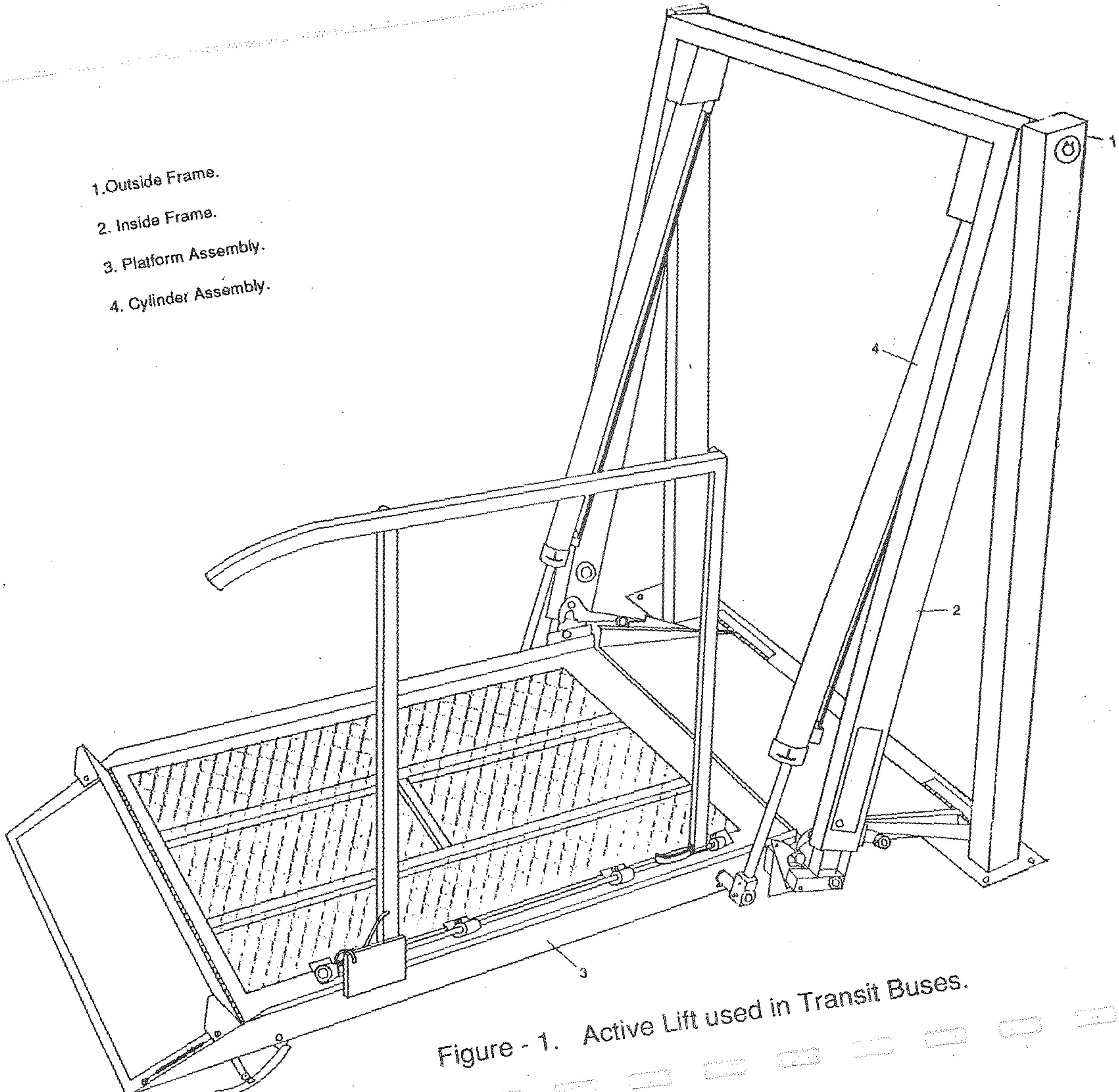


Figure - 1. Active Lift used in Transit Buses.

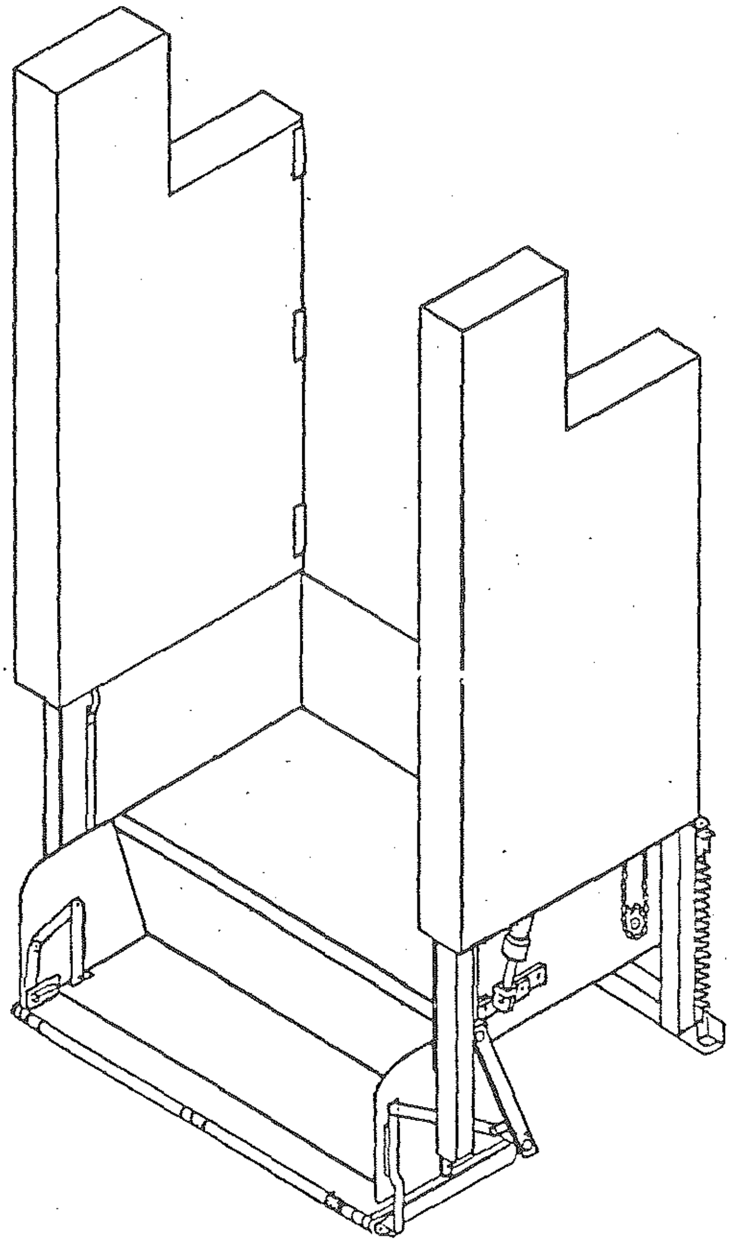


Figure - 2. Passive Lift used in Transit Buses.

Lift or Wheel Chair Lift: A level change device used to assist those with limited mobility in the use of transit and paratransit services. The term lift and wheelchair lift are used interchangeably.

Automatic Lift: This term refers to a lift that has powered up, down, fold and unfold functions.

1.2 Problem Statement:

There is a concern today that wheelchair lifts, whether active or passive, sometimes become inoperative. While the exact nature of the problems related to these lifts are not documented in the literature, there is a common perception that these problems are not the consequence of a single factor. Rather, these are caused by a combination of factors encompassing the design, manufacturing, operation and maintenance of these lifts. In addition, compatibility of the lift life span with the bus life span is a cause of concern to all operators.

This issues related to the lift reliability is a significant concern especially for small size operators. Platform lifts are commonly installed in small to mid-size transit buses that are operated by small-size non-urban systems. The fleet size and other operational constraints of the small operators necessitate very reliable wheelchair lifts for uninterrupted service to the handicapped. A non-urban operator with a typical fleet size of 10-15 buses cannot offer reliable service, even if one lift becomes non-operational. Typically, these operators do not have vehicles in reserve in the event of an emergency situation, such as lift failure.

1.3 Purpose Of Study:

The study was commissioned jointly by the US Department of Transportation and the Michigan Department of Transportation (MDOT), primarily as a fact-finding mission to assess the nature and magnitude of the problems related to wheelchair lifts. The federal funding for this project was made available through the Great Lakes Center for Truck Transportation Research(GLCTTR), at the University of Michigan Transportation Research Institute. An investigation of the design, operation and maintenance of wheelchair lifts is conducted in this study. The broad purpose of this project to be conducted in three phases is two fold:

(1) To assess the nature of the problems pertaining to any one or the combination of the design, manufacturing, operation, maintenance of wheelchair lifts of transit buses.

(2) To propose upgrade needs or operational changes to alleviate the service problems associated with the wheelchair lifts.

This report describes the findings of the Phase I study and addresses the problem identification process designed to examine the serviceability of wheelchair lifts based on an engineering analysis of the lift mechanism. The engineering analysis was conducted by developing a computer based finite-element model. Additionally, a statistical analysis of a select sample of lift repair data is presented for the development of a reliability model.

1.4 Methodology:

The approach taken to attain the study objects can be briefly described as a series of sequential steps as follows:

Step 1 - Operator Survey: A number of transit operators (mostly non-urban operators as directed by MDOT) were interviewed for their input to the problem identification process. For this purpose, a comprehensive list of survey questions was prepared addressing issues of design, manufacturing, maintenance, and operation of wheelchair lifts. The questionnaire survey was conducted on site with personal visits to transit operator offices.

Step 2 - Compiling Technical Information: Through a formal library search process, a variety of technical information on wheelchair lifts was compiled. Much of the technical data thus compiled was used in the understanding of the behavior of the structural components and in the development of the finite element model.

Step 3 - Manufacturer Survey: A limited survey among the major wheelchair lift manufacturers in the U.S. was conducted. The survey was originally intended to be used to review the process of design and manufacturing of wheelchair lifts and their conformance to federal standards. Other objectives of this survey were to assess the manufacturer's perception on the probable causes of lift failure and to determine the possible impact of emerging technologies on the design and manufacturing process of these lifts. Unfortunately the survey results were of little consequence to the project because of a poor response.

Step 4 - Engineering Analysis of Structural/Mechanical Components: The purpose of this task was to identify specific operating components of the wheelchair lifts where failure/malfunctioning is likely to occur. The structural, mechanical and sensing components of the lift were analyzed.

Step 5 - Analysis of Repair Data: Available data on maintenance/repair of wheelchair lifts was collected from two operating agencies in Southeast Michigan. The data thus collected was analyzed to discern possible patterns in the maintenance needs of the wheelchair lifts and for the development of a lift reliability model.

Results of the above analysis are presented in the following chapters.

2. TRANSIT OPERATORS SURVEY

2.1 Introduction:

The literature search process indicated the existence of a variety of lifts that are currently available for assisting handicapped passengers board transit buses as well as other structures, e.g. elevators, stairs ,etc. Initial discussion with MDOT personnel, and a number of bus manufacturers resulted in the identification of ten major lift manufacturers in the country. Product brochures and other technical information on these lifts were collected initially from the library and later by establishing contact with these manufacturers.

Table 1 shows the essentials of the technical data compiled on the lifts available from the ten manufacturers. This table indicates:

For platform lifts the platform dimensions vary slightly between 29" x "40 to 32" x 45".

The operating load (maximum live load the lift is assigned to carry) is specified from a low of 600 lb to a high of 750 lb.

The mechanism for lift control in most cases is either electrical/hydraulic or electrical/mechanical type with a switch device for the lift operation. In a few cases driver control mechanism is also used.

There is a significant price variation between lifts. Particularly, there is substantial price differential between platform lifts used for small buses and folding lifts used for the larger full size transit buses.

2.2 Survey Of Transit Operators

A list of survey questions was specially designed for transit operators in Michigan to elicit their viewpoints, comments on the operation of wheelchair lifts, (Appendix A). A total of six operators with their fleet size varying between 10 to 224 were visited by the project team. Table 2 shows the list of agencies visited, their respective bus fleet sizes and the type of lifts used for wheel chairs. The project team consisting of the two CO-PI's and the graduate research assistant visited these agencies and conducted a comprehensive interview with a representative of the agency that required approximately two hours of meeting time. The object of the formal questionnaire survey was to maintain consistency among the operators in the nature and types of the questions. Personal visits by the project team to the site provided a better understanding of the general operation of the transit agency. Table 3 shows a summarized version of the responses received from the operators. In addition to the results compiled in Table 3, the following are the summary of additional observations:

(a) The operators expressed their concern about the needs of the handicapped, and appear to follow manufacturer-recommended maintenance procedures for the wheelchair lifts.

(b) The smaller operators with their constrained resources, and often with limited facilities face the prospect of serious service disruption in the event of a lift malfunction, because of the very little spare factor associated with their fleet.

(c) Larger operators are better equipped with manpower and maintenance/repair facilities and are not affected as adversely as the small operators in the event of lift malfunctions.

Table-1. Technical Information on Lifts

COMPANY	LIFT INFOMATION					
	Size	Lift Type	Weight (lb)	Control*	Operating Load(lb)	Price ($)
1. Time Saver Products Inc.	S	Platform 30" X 40"	300	E-H S	600	1,295
2. Braun Corp.	S	Platform 30" X 44" & 33" X 44"	360	E-H G S	750	2,475
3. Collins.	S	Platform 30" X 45" & 32" X 45"	370	E-H S	750	2,675
4. Reb Manu.Inc.	S	Platform 30" X 42"		E-H S	600	1,860
5. Ricon Corp.	S	Platform 30" X 40"	170	E-M S	600	3,325
6. Crow-River	S	Platform 27" X 41" & Platform 30" X 39"	235 295	E-M S	600 750	2,750
7. Lift-U	L	Step 32" X 51"	NA	E-H D	600	12,000
8. TMC Inc.	L	Step	NA	E-H D	750	NA
9. Mobile Tech Corp.	S	Platform 30" X 45"& 32" X 45"	370	E-H	750	NA

* E-h = Electric/Hydraulic
E-m = Electric/Mechanical
S = Switch Control
D = Driver Control
G = Gravity Down

Table-2. Agencies Visited and Respective Fleet sizes, Common Lift Brands

AGENCIES (Location)	LIFT TYPE	Fleet Size (N)
SMART (Southeast Michigan)	TMC and LIFT-U (Large Buses) COLLINS (Small Buses)	224
LECT (Howell)	REB	10
EATRANS (Eaton County)	REB & COLLINS	15
SCTC (Sanilac County)	REB & COLLINS	10
HURON TRANS (Huron County)	REB & COLLINS	19
AATA (Ann Arbor)	ORION, TMC, LIFT-U, EEC	64

** Other Manufacturers : RICON, TIME SAVER,
CROW-RIVER, TER/ PREVOST.

Table-3. Operators survey.

NAME	FLEET AGE	PROCURE SPECS.	TRAINING PROGRAM	LIFT MAINTENANCE SCHEDULE	PROBLEMS	CAUSES
1	10 Years	AMTMS	YES	Follows maintenance schedule well.	No Serious problems.	NA
2	3 Years	SMART	YES	As and when needed	Electrical system, hydraulic pump cylinder system,frame jerk &swing.	Operation area is rural-dirt gravel.
3	3 Years	MDOT	YES	Follows maintenance schedule. Lifts. lubricated every two months or 3000 miles.	Electrical system , pump oil link, connecting pins, frame jerk.	Inability of retraction mechanism to retain position during loading & insufficient shear strength of the pin connections.
4	3 years	MDOT	YES	NA	NA	NA
5	2 year	MDOT	YES	Follows the maintenance manual. Lifts lubricated once in 3 months.	electrical problems, transmission flow leaking.	NA

(d) The operators recognize the importance of proper training of the mechanics for the wheelchair lifts maintenance and repair. This is evident from in-house training programs that they undertake and their participation in regional training programs, over and above the training usually recommended and sometimes provided by the lift manufacturer.

(e) Most of the operators have a staffed maintenance/repair shop. However, the scope of the shop could vary from a full scale operation of major maintenance/repair service to a very basic repair capability. The latter case, pertains to the smaller agency where, the operator either privately contracts for major repair services or seeks technical assistance from the regional transit agency, (if administratively possible). Staffing of maintenance/repair shop in most cases is inadequate.

(f) The extent of usage of the wheelchair lifts usually varies with the size of the operator, or more appropriately with the size of the population with impaired mobility. However, there appears to be some uniformity of usage over a period of a week for the same operator. For the smaller agency, many of whom operate on a para-transit mode, the lifts are used at least once per day. For the larger operator, with fixed route service, the usage rate varies with the specific routes. In most cases, the lifts are 'cycled' at least once a day at the maintenance yard before the vehicle is dispatched for service. However, accurate data on lift usage per vehicle is not available.

(g) Specific types of problems mentioned by the operators discussed during interviews include the following:

- Electrical System
- Hydraulic System
- Transmission Leakage
- Hydraulic Oil Leakage
- Pin Connectors
- Retraction Mechanism
- Terrain/Topography
- Unpaved Road/Gravel Surface
- Adverse Weather (Rain/Snow)

2.3 Survey of Manufacturers:

A mail-back survey was conducted among a group of select lift manufacturers with the objective of obtaining both factual as well as opinion type data on various aspects of lifts. The survey questions are included in Appendix B. Specifically, the survey, that was mailed to a total of nine manufacturers, addressed questions on design standards, performance evaluation and maintenance procedure. After two mail-back attempts only three returns were obtained. On the basis of three responses the following comments can be made:

a) Sales volume of the three respondents totals 2000 wheel chair-lifts including small, medium and large transportation buses. This sales volume includes both step and platform lifts.

b) The UMTA Guideline Specifications for wheelchair lifts is the basis for manufacturer specifications.

c) The product life varies between 8 to 12 years, (one manufacturer provided product life in terms of number of cycles).

d) No uniformity was observed for maintenance personnel qualifications. However, all firms provide maintenance training manuals and courses.

e) All manufacturers indicated that minimal amount of training is required for operating lifts. Training material in the form of videos and manuals are commonly provided by the manufacturer.

The two issues of primary importance here are the nonuniformity in the definition of product life and the extensive dependence on the UMTA specifications for product development. The UMTA document was developed and published in 1986 and represents an initial effort by the U.S. Dept. of Transportation to provide minimal guidelines. Continuous developments and updates to the specification are essential in view of changes in need, use and technology.

3. STATISTICAL ANALYSIS OF REPAIR DATA

3.1 Introduction:

An effort was made during the visits to the transit agencies to determine the availability and quality of wheelchair lift repair data. It was clear from the discussion with the transit agencies, that the larger operators are more likely to have a comprehensive data base on maintenance and repair of lifts. As such a decision was made to investigate the repair data available from one of the two larger operators in Southeast Michigan. They are the Suburban Mobility Authority for Regional Transportation (SMART), the regional transportation agency for the Detroit Metropolitan area and the Ann Arbor Transportation Authority (AATA), the transportation agency for the Ann Arbor area. The object of the analysis conducted with the repair data was three fold.

(1) To determine if there is a statistical pattern in the frequency and distribution of repair needs of wheelchair lifts.

(2) Assuming the existence of a pattern, is it possible to develop a reliability model that can be used for predicting future repair needs?

(3) To determine if there are significant differences between the distribution of repair needs of different types of lifts.

A decision was made to utilize the SMART data base for the above analysis primarily because, of the availability of the data base that would lend itself answering the above questions.

3.2 SMART Data Base:

The individual repair records of the SMART data base on wheelchair lifts were reformatted and recast in a new data file using the dBase III Plus software. The SMART data base included the following information:

1. Time period - 5 years (January 1, 1985 thru December 31, 1989)
2. Type of lift Repair for the following codes:
    . General (Code 189)
    . Electrical (Code 190)
    . Mechanical (Code 191)
    . Body (Code 192)
    . Hydraulic (Code 193)
3. Date of the Repair
4. Mileage on the day of the Repair
5. Expenses incurred by:
    . Labor hours
    . Parts

The above data was obtained from SMART for two types of passive lifts (Type A & B), for five large transit buses in each category making a total of 10 buses. The ten buses were selected at random from a population of over 200 buses. Note, that the repair data obtained from SMART does not include the information on regular maintenance conducted at fixed intervals; usually every 3000 miles. The data was then recast using the dbase III plus software and a sample of the data base thus created is presented in Table 4. Table 4 essentially includes information on the date of the repair, mileage and expenses incurred in each of the five repair categories, represented by codes 189, 190, 191, 192, and 193 as explained above.

A review of the current literature indicates that for engineering analysis of repair data, two primary variables, i.e. "miles elapsed between successive repairs" and "time elapsed between successive repairs" are used as the indicator of longevity of lift components. In the rest of this report the above two distributions will be referred to as 'Miles Between Repair' (MBR) and 'Time Between Repair' (TBR). The repair cost data included in the data base was not used in

Table - 4. Sample Listing of Lift Repair Data. (Expenses Incurred in Dollars by Repair Code)

Date	Mileage	Code 189.			Code 190			Code 191			Code 192			Code 193		
		Maj.	Ave.	Min.	Maj.	Ave.	Min.	Maj.	Ave.	Min.	Maj.	Ave.	Min.	Maj.	Ave.	Min.
05-06-85	141000			25.6												
02-03-86	183000			12.8												
06-11-86	199000												32.2			
08-26-86	210400												23.1			
10-07-86	214800			44.5							1090					
04-09-87	240000			26.0												
08-04-87	257000		62.1									57.0				
10-14-87	268000										267.					
12-03-87	277500											96.5				
02-25-88	288300		102.							22.0		146.				
07-22-88	310000						6.26			25.1						

the statistical analysis presented below, primarily because of a wide variance in the distribution. Further, miles and time elapsed, rather than cost incurred is viewed as key indicators in the literature in of the reliability analysis. An effort was made to segregate the MBR and TBR data by cost; however. This effort was discontinued later as the resulting sample size became too small for statistical validity.

The MBR and TBR data was initially analyzed to conduct some basic statistical evaluation. Table 5 shows the mean and standard deviation of the TBR and MBR distributions of the five lifts for Type A & Type B Category, for all repairs codes (189 through 193). The means of the two distributors will be referred to as Mean Time Between Repair (MTBR) and Mean Miles Between Repair (MMBR) in the report. Also included in Table 5 are: beginning mileage and date, end mileage & date, number of repairs conducted during the 5 year period (N) and number of repairs per month (n). Finally the grand mean values for the appropriate columns are also presented in Table 5.

Table 5 indicates some interesting trends that deserve attention. First, the consistency in the values of the MTBR and MTBR and their corresponding variances in clearly noteworthy, inspite of the difference in the number of times that repair was needed, (N-value). Secondly, lift Type A appears to have higher longevity than Type B. A review of the grand mean values shows, that for Type A lifts, on the average a repair was warranted every 2.43 months or every 11,086 miles. The corresponding figure for Type B lift is 1.46 months or 7150 miles. Thirdly, the number of repairs needed for the same 5 year period for type A is less than that for Type B. Type A Lift needed a repair at the rate of 0.42 times / per month; the corresponding figure for Type B is 0.71 times / month. The above data indicates that the reliability of Type A is higher with less frequent repairs and higher MTBR and MMBR values than Type B. Lastly, there is significant difference in the number of miles driven per month for buses equipped with type A lift compared to those with Type B. Although not included in Table 5, calculations indicated that for buses equipped with lift Type A, the average number of miles driven per month is 4310, the corresponding figure for Type B is 3410.

The repair data was collapsed into two subgroups; (1) for all repairs conducted under the 'general' category (code 189) and (2) those under all other categories (code 190 thru 193). The collapsed data is presented in Table 6 and 7. The reason the last four categories were grouped together was to ensure that resulting data base contains a large enough sample size to lend statistical validity to the results obtained. The data presented in Table 6 & 7 can be interpreted in the same way as that already discussed in Table 5. As in the previous case, Table 6 and 7 also appear to suggest that the repair needs for lift B are more frequent than those for A. It is however, possible that the cost of the repair for Type B was substantially different from that for A. Although necessary data for investigating this factor is contained in the file created, it was considered beyond and the scope of this analysis to investigate the cost data (within the confines of the project duration). It would suffice to add here, that the frequency of repair data alone (without due consideration of the cost data) should not be used for conclusions regarding the higher reliability of lift A compared to B. Additionally, a rigorous cost effectiveness analysis, if conducted for two lift brands should also include the capital costs.

3.3 Mathematical Basis:

Weibull distribution is a common tool for reliability analysis of machine components. Weibull distribution was originally proposed for interpretation of fatigue data, and later extended to a variety of engineering problems, particularly those dealing with service life phenomena [4]. Past research has shown that the Weibull distribution describes well the characteristic life of individ-

Table - 5. Summary of Repair Data for Type A and Type B Lifts.(All repairs together).

Lift No:	Beginning		TBR (months)		MBR (miles)		N	n(repairs/	End	
	Date	Mileage	Mean	Std. Dev.	Mean	Std. Dev.	# repairs	month)	Date	Mileage
A-1	04-13-85	174,400	2.806	4.247	12,901	19,190	19	0.375	12-15-89	419,500
A-2	04-05-85	180,000	2.306	2.078	10,330	9,405	23	0.434	09-21-89	416,400
A-3	02-04-85	168,600	1.953	2.579	7,940	9,729	30	0.535	12-15-89	406,840
A-4	01-03-85	166,200	2.251	2.096	9,848	7,264	26	0.441	12-15-89	412,300
A-5	05-06-85	141,000	3.034	2.276	14,411	9,573	18	0.327	12-06-89	386,000
Grand Average:			2.430	2.654	11,086	11,032	23.3	0.422		
B-1	01-08-85	91,700	1.245	1.388	5,776	6,508	49	0.881	12-04-89	291,690
B-2	01-02-85	86,700	1.820	1.675	8,722	8,176	33	0.559	12-13-89	296,500
B-3	12-27-84	86,300	1.353	1.429	6,824	6,998	45	0.717	12-18-89	295,300
B-4	01-24-85	92,800	1.415	1.710	7,157	8,401	41	0.695	12-13-89	297,500
B-5	01-28-85	117,100	1.455	1.213	7,270	6,259	41	0.695	12-19-89	301,600
Grand Average:			1.457	1.483	7,150	7,268	41.8	0.710		

Table - 6. Summary of Repair Data for Type A and Type B Lifts.(General repair code-189 only).

Lift No:	Beginning		TBR (months)		MBR (miles)		N	n(repairs/	End	
	Date	Mileage	Mean	Std. Dev.	Mean	Std. Dev.	# repairs	month)	Date	Mileage
A-1	04-13-85	174,400	3.500	4.570	15,320	20,120	16	0.2857	12-15-89	419,500
A-2	04-05-85	180,000	2.527	2.117	11,310	9,540	21	0.3963	09-21-89	416,400
A-3	02-04-85	168,600	2.657	3.111	10,830	11,510	22	0.3928	12-15-89	406,840
A-4	01-03-85	166,200	2.706	2.742	11,190	9,960	22	0.3728	12-15-89	412,300
A-5	05-06-85	141,000	4.550	2.857	20,420	12,770	12	0.2182	12-06-89	386,000
B-1	01-08-85	91,700	1.668	1.584	7,260	7,500	39	0.6610	12-04-89	291,690
B-2	01-02-85	86,700	2.071	1.782	9,930	8,770	29	0.4915	12-13-89	296,500
B-3	12-27-84	86,300	1.896	1.937	8,960	9,240	32	0.5340	12-18-89	295,300
B-4	01-24-85	92,800	2.075	2.213	10,280	10,740	28	0.5957	12-13-89	297,500
B-5	01-28-85	117,100	1.608	1.364	8,060	6,920	37	0.6270	12-19-89	301,600

Table - 7. Summary of Repair Data for Type A and Type B Lifts.(All other repairs together).

Lift No:	Beginning		TBR (months)		MBR (miles)		N	n(repairs/	End	
	Date	Mileage	Mean	Std. Dev.	Mean	Std. Dev.	# repairs	month)	Date	Mileage
A-1	06-17-86	229,100	3.06	5.140	13,610	23,100	14	0.334	12-15-89	419,500
A-2	10-10-85	211,600	3.90	3.610	17,170	15,870	21	0.255	09-21-89	416,400
A-3	02-04-85	168,600	2.659	4.103	10,770	15,550	22	0.379	12-15-89	406,840
A-4	01-03-85	166,200	3.903	3.663	16,430	14,580	15	0.254	12-15-89	412,300
A-5	02-23-86	141,000	3.462	2.385	15,620	10,620	13	0.282	12-06-89	386,000
B-1	10-22-85	54,400	1.735	1.735	6,970	8,050	35	0.700	12-06-89	291,690
B-2	05-28-86	90,500	4.100	4.180	19,660	20,890	8	0.242	02-02-89	247,800
B-3	07-22-86	99,900	1.744	1.457	8,140	6,890	24	0.585	12-18-89	295,300
B-4	03-10-85	51,000	2.172	2.546	10,790	13,110	26	0.448	12-13-89	297,500
B-5	04-12-85	21,400	2.106	2.456	10,530	12,820	27	0.482	12-19-89	301,600

ual machine components, while the exponential distribution (that can be shown to be a special case of Weibull distribution) is better suited to explain levels of assemblies or systems. The Weibull density function is of the form:

$$f(x) = \left[\left(\frac{b}{\theta - x_0}\right)\left(\frac{x - x_0}{\theta - x_0}\right)^{b-1}\right]\left\{\exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^{b}\right]\right\} \quad (1)$$

Where the parameters, x_0, b, are determined empirically or experimentally.

x_0 is the expected minimum value of x, often referred to as the location parameter.

b is the Weibull slope, referred to as the shape parameter.

θ Is the characteristic value, or scale parameter. (Figure 3)

The cumulative distribution function, derived by integrating equation (1) is:

$$F(x) = \int_{-\alpha}^{x} f(x)dx = \int_{x0}^{x} f(x)dx$$

$$F(x) = \int_{x0}^{x}\left(\frac{b}{\theta - x_0}\right)\left(\frac{x - x_0}{\theta - x_0}\right)^{b-1} \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^{b}\right]dx$$

Now, suppose:

$y = \left(\frac{x - x_0}{\theta - x_0}\right)^{b}$, then

$$dy = b\left(\frac{x - x_0}{\theta - x_0}\right)^{b-1}\left(\frac{1}{\theta - x_0}\right)dx$$

or

$$F(x) = \int e^{-y} dy$$

Which yields:

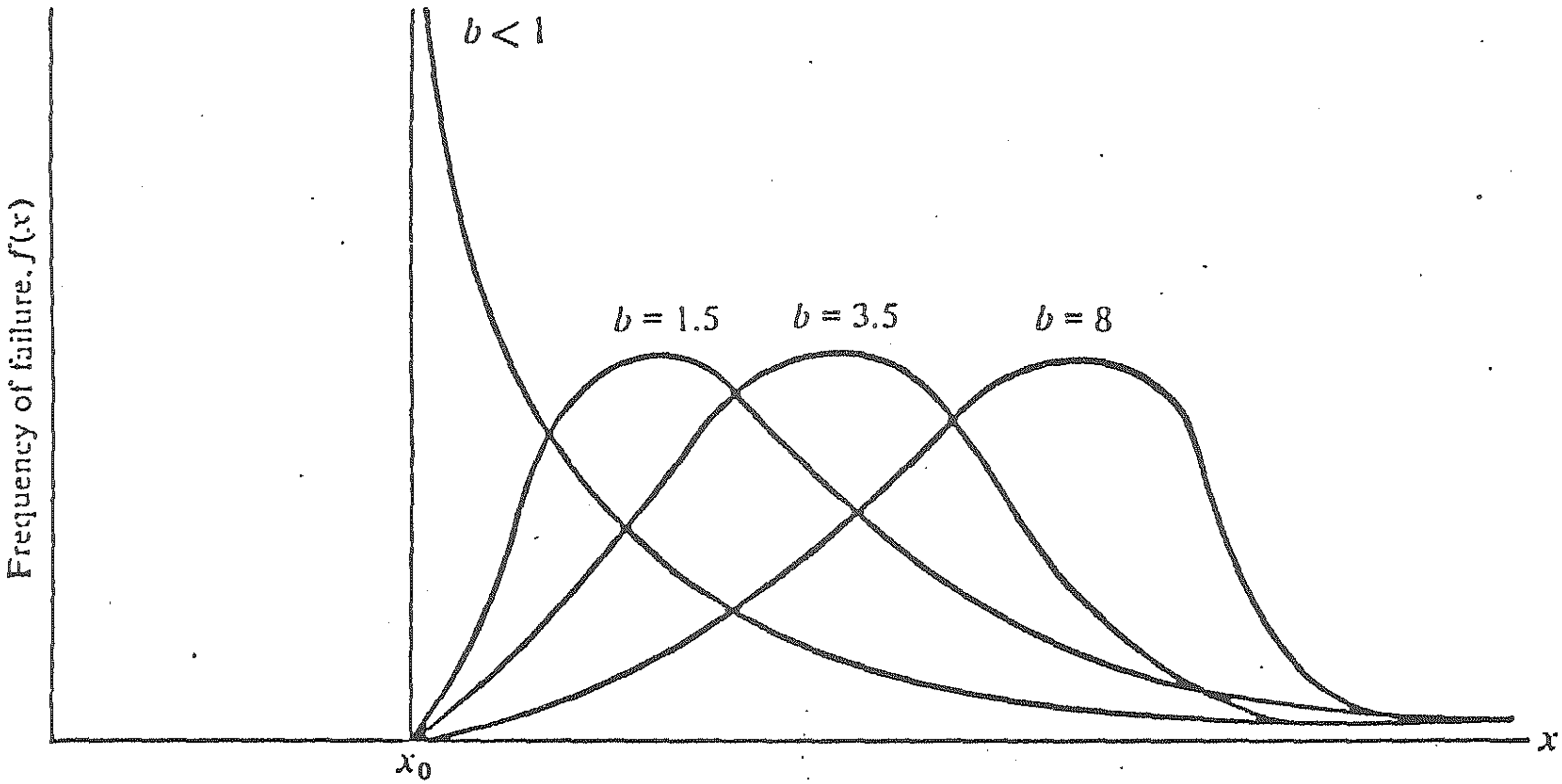


Figure-3. The density function of the Weibull distribution.(Source - 4)

$$F(x) = 1 - \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right] \tag{2}$$

To simplify the model development process empirically, it is sometimes assumed that the lower bound of life x_0, the expected minimum of the population is zero. This assumption reduces the Weibull cumulative distribution function specified in equation (2) to:

$$F(x) = 1 - \exp\left[-\left(\frac{x}{\theta}\right)^b\right] \tag{3}$$

Equation 3 is a simplified version with two parameters compared to the three parameter function specified in (2). Equation (3) can be rewritten as:

$$\left(\frac{1}{1 - F(x)}\right) = \exp\left(\frac{x}{\theta}\right)^b$$

Taking natural logarithms,

$$\ln\left(\frac{1}{1 - F(x)}\right) = \left(\frac{x}{\theta}\right)^b$$

$$\ln\ln\left(\frac{1}{(1 - F(x))}\right) = b(\ln x) - b(\ln\theta) \tag{4}$$

equation (4) has a form

$$Y = bX + C \tag{5}$$

where, $Y = \ln\ln\left(\frac{1}{1-F(x)}\right)$

$$X = \ln x$$

$$C = -b \ln \theta \qquad (6)$$

The equation $Y = bX + C$ represents a straight line with a slope b and intercept C on the cartesian X, Y coordinates. Hence, a plot of

$$\ln \ln \left(\frac{1}{1 - F(x)} \right)$$

against $\ln x$ will also be a straight line with slope b. Thus, the parameter b in the Weibull function is referred to as the slope parameter. Figure 4 demonstrates different numerical values of Weibull slope. It can further be shown that when b equals one, the Weibull distribution becomes an exponential function, and that at $b = 3.5$, it becomes a normal distribution.

To determine the probability that a part will fail at the characteristic life or less, from Eq. (3) for $x = \theta$

$$\begin{aligned} F(x) &= 1 - \exp\left[-\left(\frac{x}{\theta} \right)^b \right] \\ &= 1 - \exp\left[-\left(\frac{\theta}{\theta} \right)^b \right] = 1 - e^{-1} = 1 - \left(\frac{1}{e} \right) \\ &= 1 - \left(\frac{1}{2.718} \right) = 0.632 \\ &= 63.2\% for x = \theta \end{aligned} \qquad (5)$$

Thus,θ, the characteristic life is the life by which 63.2% of the parts will have failed. Lastly, as stated before, the plot of

$$Y = \ln \ln \left(\tfrac{1}{1 - F(x)} \right) \text{ vs. } x = \ln(x)$$

is a straight line with a slope *b*. A special coordinate paper, known as the Weibull Probability paper, with a logarithmic abscissa scale and an ordinate scale transforming *F(x)* to

$$\ln\ln\left(\frac{1}{1-F(x)}\right)$$ is generally used to plot the distribution.

Hence a Weibull variable x, plotted versus *F(x)* on this paper will be represented as a straight line with a slope *b* as demonstrated in Figure 4.

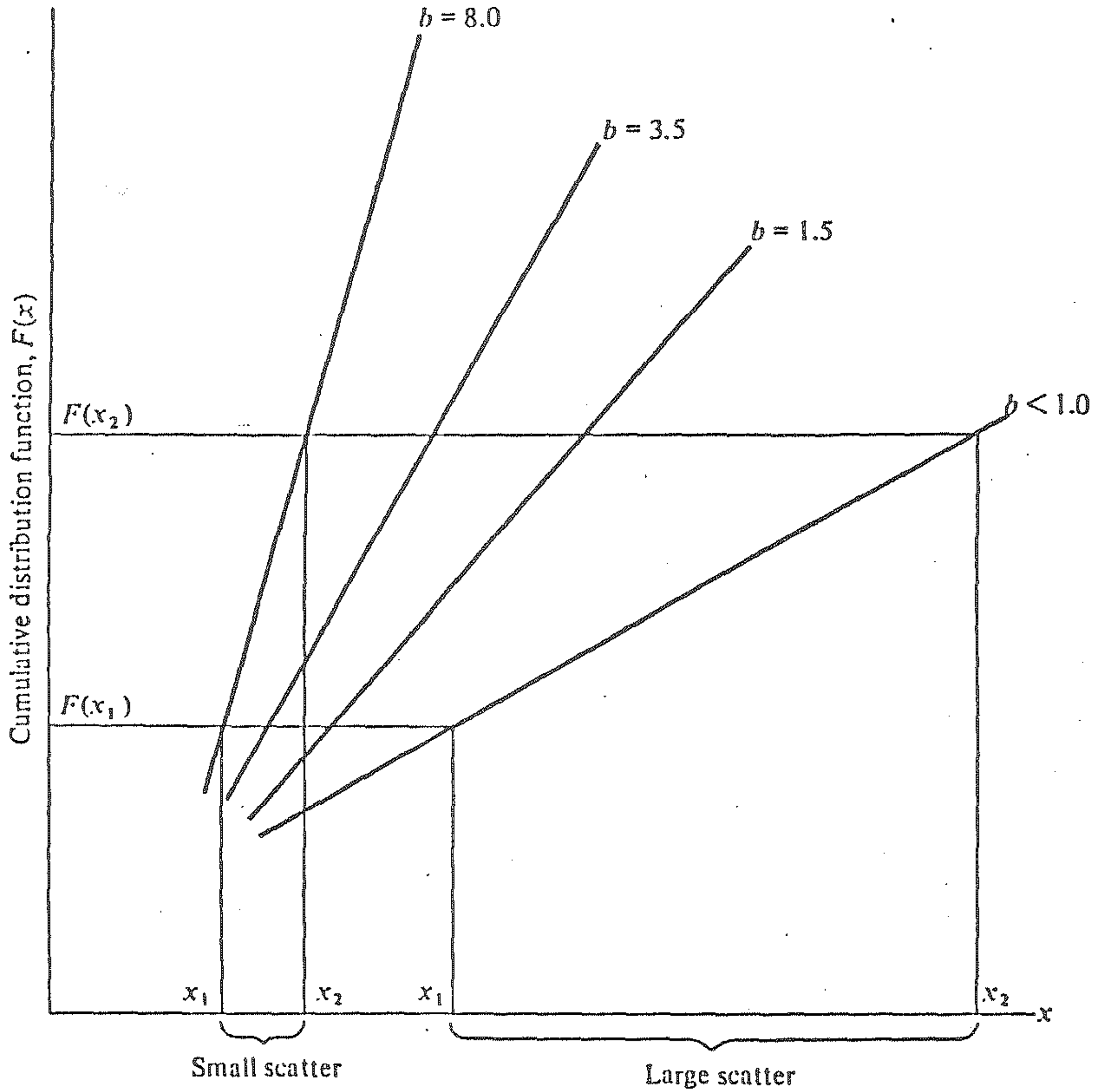


Figure-4. Weibull plots for various slopes on Weibull probability paper.(Source - 4)

4. WEIBULL TEST WITH LIFT REPAIR DATA

4.1 Introduction:

A sample of the TBR and MBR data, retrieved from the SMART data base, when plotted on Weibull probability paper as described in the previous section appeared to suggest a linear relationship typically expected of Weibull distribution. A decision was made to apply the Weibull distribution to mathematically explain the repair needs of wheelchair lifts. A few crucial assumptions were made before Weibull testing was conducted:

(1) Current literature suggests that, Weibull appears to better explain failure of component data as opposed to system data. This is not to say however, that system would not fit Weibull distribution. Whether a lift is a component or a system is indeed a matter of opinion. If one considers the bus to be an integrated system comprising the engine, the chassis, transmission, brakes, etc. and the wheel chair lift, then each of the above entities could be considered a component. On the other hand, each of the above entities in its own right could be looked upon as a subsystem with subcomponents. Thus a lift could be considered a subsystem consisting of subcomponents such as this platform, the lifting device, the control mechanism etc. For the purpose of this research, the lift was assumed to be a component.

(2) Ideally, Weibull distribution explains failure data when a component after failure, is replaced with a new component, and the old component is discarded. A lift on the other hand, does not fail generally in its entirety, and is not discarded. Rather, repairs are conducted as and when needed. For the purpose of the statistical analysis, it was assumed that following a repair, the lift becomes functionally a new component.

(3) The regular preventative maintenance on the lift that is conducted by the agency, is not included in the data base. To what extent, if any such regular maintenance may have affected the repair needs of the lifts can only be estimated by comparing the repair data for lifts with and without regular maintenance. Since such data is not available, it is not possible to assess the effects of regular maintenance on lift reliability. It is assumed that regular maintenance reduces the need for unscheduled repairs, and hence in the absence of such regular maintenance, the frequency of repair would be different.

Both the MBR and TBR data were analyzed for their correspondence with Weibull distribution. A software entitled 'Qualitek 2' ; developed by a Michigan based corporation NUTEK donated to the Department of Civil Engineering, Wayne State University by NUTEK was used for this purpose. 'Qualitek 2' is a comprehensive software used extensively for failure data analysis, and can, among things develop the Weibull parameters (slope, and characteristics life), given appropriate failure/repair data. It can also test the goodness of fit of the Weibull model developed and can generate confidence bands of expected lives of the component for various levels of statistical significance [8].

4.2 <u>Analysis of MBR Data</u>:

Summarized versions of the Weibull test results of repair data of MBR distribution for the 10 lifts (5 for Type A and 5 for Type B) are presented in Table 8. Figures 5 through 14, are also presented directly from the graphics output of 'Qualitek 2' representing the density function (DF) as given by equation (1), as well as the cumulative distribution function (CDF),as given F(x) in equation (2), for each of the 10 lifts analyzed. The following specific observation from this table and charts are in order:

(1) Table 8 shows that in all the ten cases there is a reasonable correlation between the dependant variable Y and the independent variable X in equation (3) as indicated by high R^2 values (coefficient of correlations). The lowest R^2 value obtained is 0.928 for lift A2, and the highest is 0.983 for lift A1.

(2) Table 8 also shows that the characteristics life, (063.2 percentile value) for Type A lifts varies from a low of 7063 miles to a high of 16,317 miles. The corresponding values for Type B lifts range from 5485 miles to 8801 miles. The composite average values of θ for the two types each consisting of five observations are 11,034 miles and 7254 miles. Furthermore a closer examination of the θ value shows that for both Type A and Type B, there are two 'outliers' each in the distribution θ, being A3 and A5 and B1 and B2. The θ values in the other 3 cases for both Type A and B are around the respective composite average of 11,034 miles and 7254 miles respectively.

In Table 5 the MMBR - value (the Mean number of Miles between Repairs) were presented for both Type A and Type B lifts. The θ -value being the 63rd percentile value of the distribution, is expected to be higher than the MMBR values. A comparison of Table 5 and 8 indicates that excepting lifts A1, A3, B1 and B4 such is the case for all other lifts. It should also be mentioned here that θ is the best estimate of the characteristic life based upon the distribution of the repair data. Thus, it is possible, but not desirable, this estimate may be somewhat different from what is expected. It appears that of the ten cases analyzed A1, A3, B1 and B4 are such exceptions where the estimated value of θ is somewhat lower than what was expected based upon the MMBR value. One possible explanation of this discrepancy is that the estimate of 'b' and 'c' in equation (5) based upon least square criteria and θ was computed using the relationship in equation (6).

(3) The slope parameter 'b' is within the proximity of unity, with 6 of the 10 values being less than one, and 4 exceeding one.

(4) Figure 5 through 14 represent the probability density function f(x) as well as the cumulative distribution function F(x) for the 10 lifts analyzed. Each figure consists of two curves, one for f(x) and the other for F(x). It should be noted that for those cases where b is less than unity, the density curve f(x) is monotonic with decreasing f(x) values with increase in x. On the other hand, for cases with b exceeding unity, the density curve attains a peak at an x-value exceeding zero, after which the curve becomes monotonic. The above feature is compatible with theoretical distribution of Weibull curves as reflected by varying value of b. (Figure 2).

(5) In Figures 5 through 14, referring to the CDF function F(x), theoretically, the characteristic life, θ should be the 63rd percentile value of the life of the lift measured by the MBR distribution. In all cases presented the above is true. For example, the 63rd percentile value for lift A1 from figure 5(a) is close to 10,000 miles, that matches the θ value of 10,075 miles as computed by this model.

(6) In Table 8, the equations developed for the linear Weibull function (equation 5) is also presented in the last column. The relationship between these equations and the parameters b and θ are as follows:

From equation (3):

Table-8. Weibull Parameters for MBR Distribution

Lift type & number	R^2	characterstic life in miles.	b slope	N	Equation Y=bX+c*
A-1	0.9839	10075.0	0.65	19	y=0.651X - 5.9961
A-2	0.9281	10811.0	1.09	23	y=1.094X - 10.1562
A-3	0.9838	7063.0	0.76	30	y=0.768X - 6.8052
A-4	0.9772	10904.0	1.41	25	y=1.412X - 13.1255
A-5	0.9609	16317.0	1.62	17	y=1.629X - 15.8052
Average		11034.0	1.106		
B-1	0.9518	5485.0	0.96	49	y=0.962X - 8.2749
B-2	0.9558	8801.0	1.00	33	y=1.003X - 9.1082
B-3	0.9776	6942.0	0.98	42	y=0.981X - 8.6752
B-4	0.9789	7066.0	1.08	40	y=1.086X - 9.6243
B-5	0.9679	7979.0	0.98	41	y=0.989X - 8.8947
Average		7254.0	1.00		

* y= ln ln (1./1 - F(x))
X = ln (x).

c = - b ln(O).

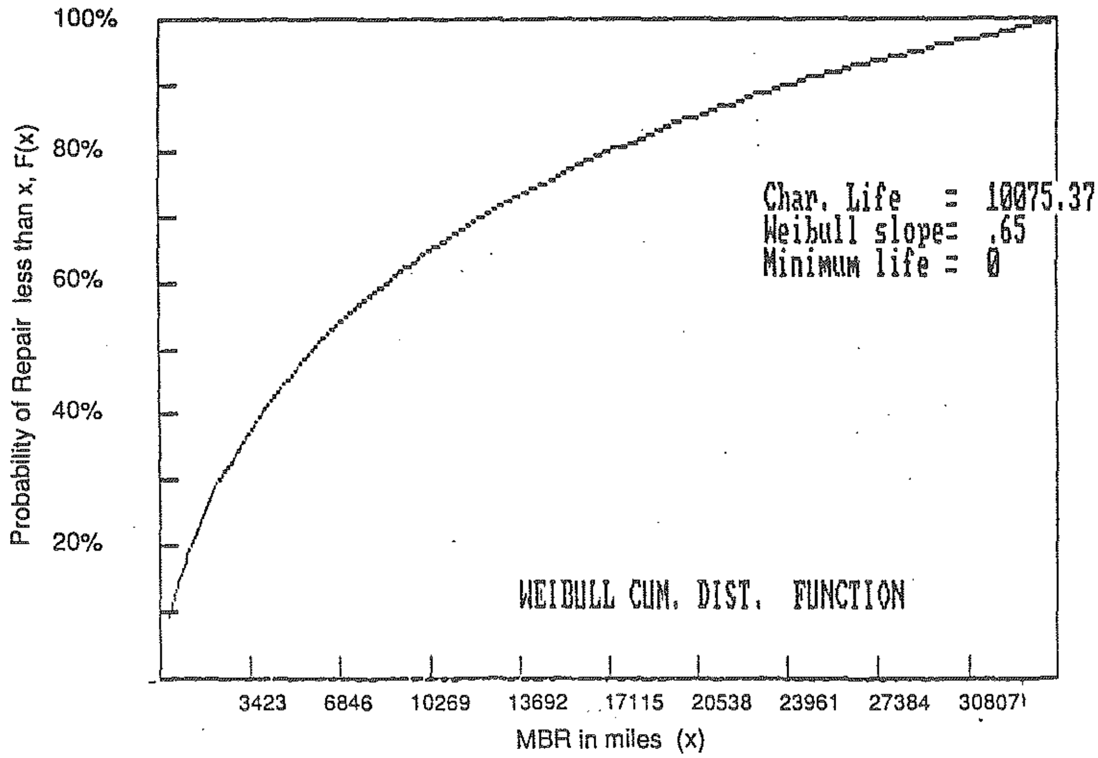


Figure-5(a). Weibull Cumulative MBR Distribution for Lift-- A1

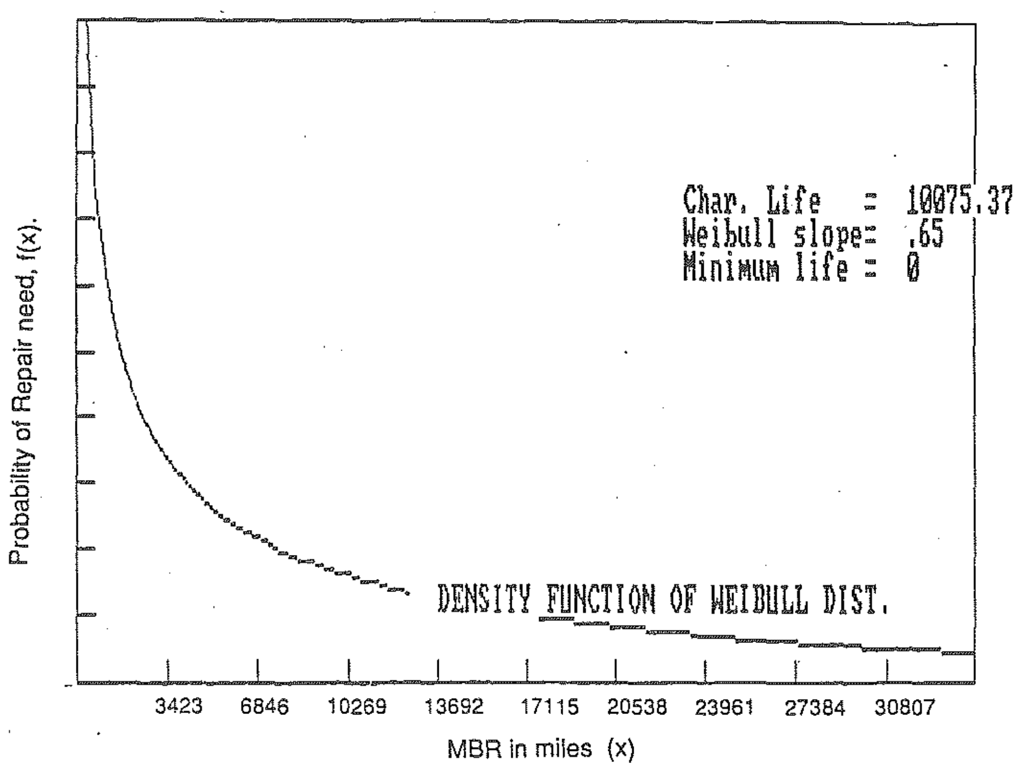


Figure-5(b). Weibull Density Function of MBR Distribution for Lift- A1

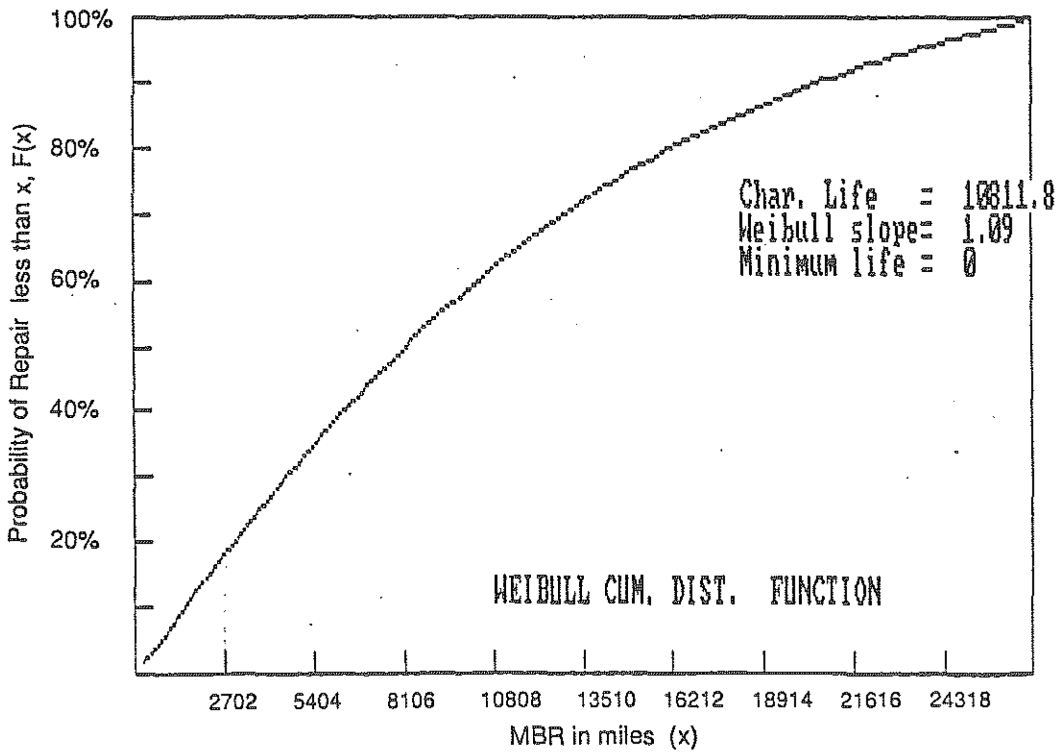


Figure-6(a). Weibull Cumulative MBR Distribution for Lift- A2

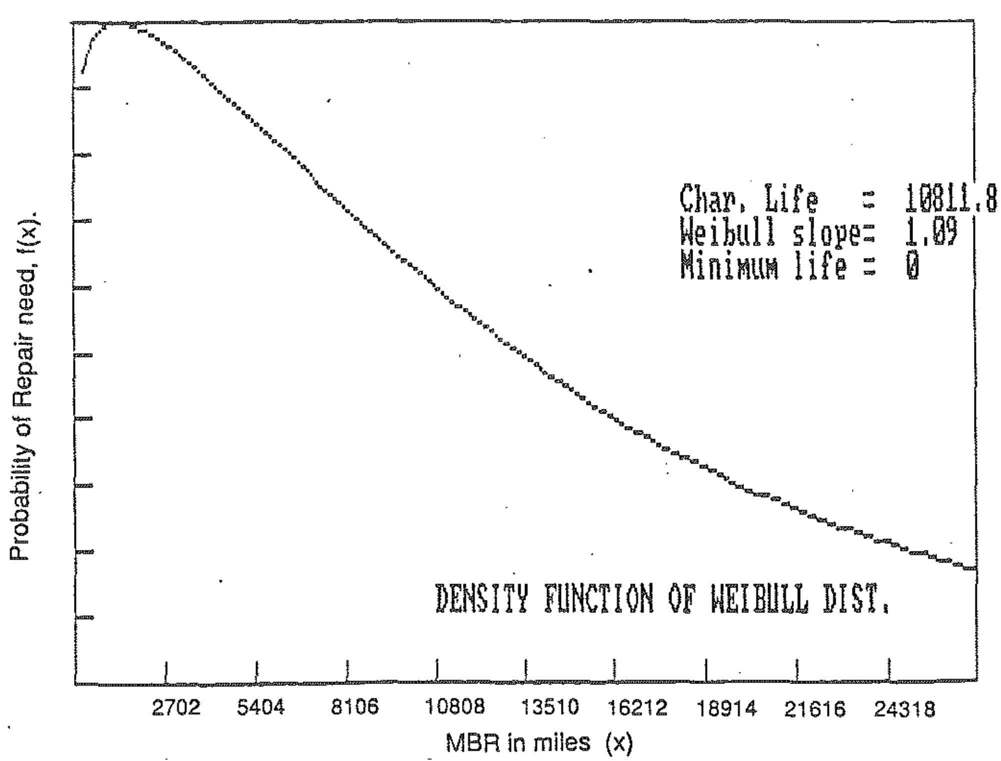


Figure-6(b). Weibull Density Function of MBR Distribution for Lift - A2

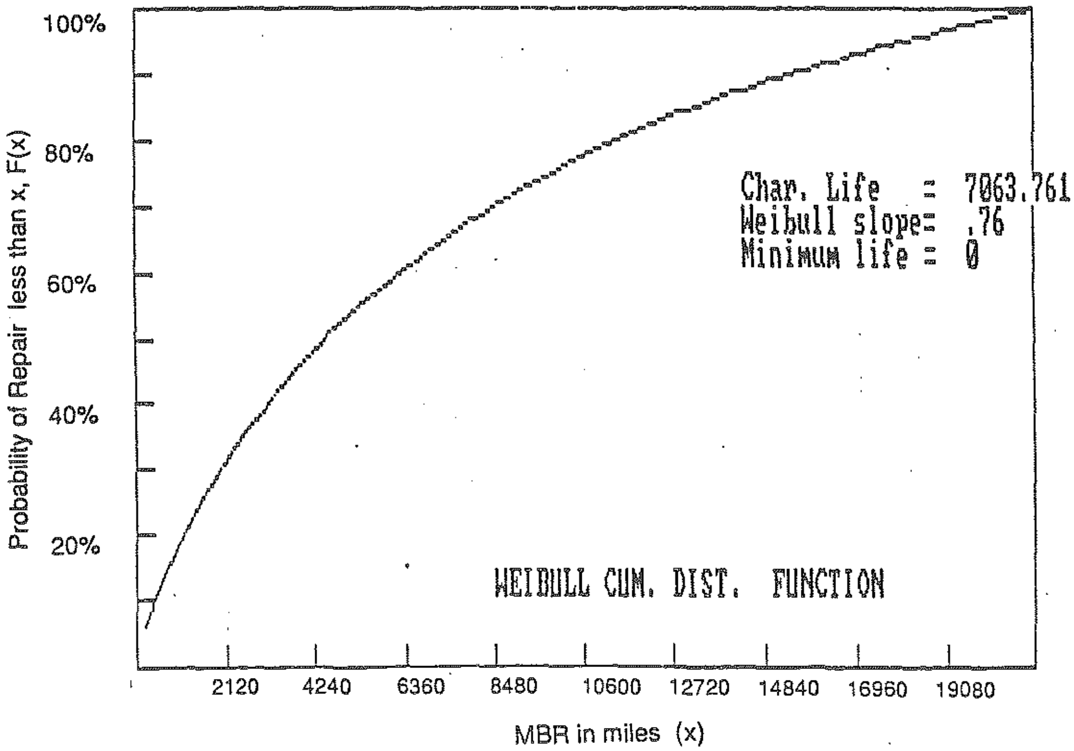


Figure-7(a). Weibull Cumulative MBR Distribution for Lift- A3

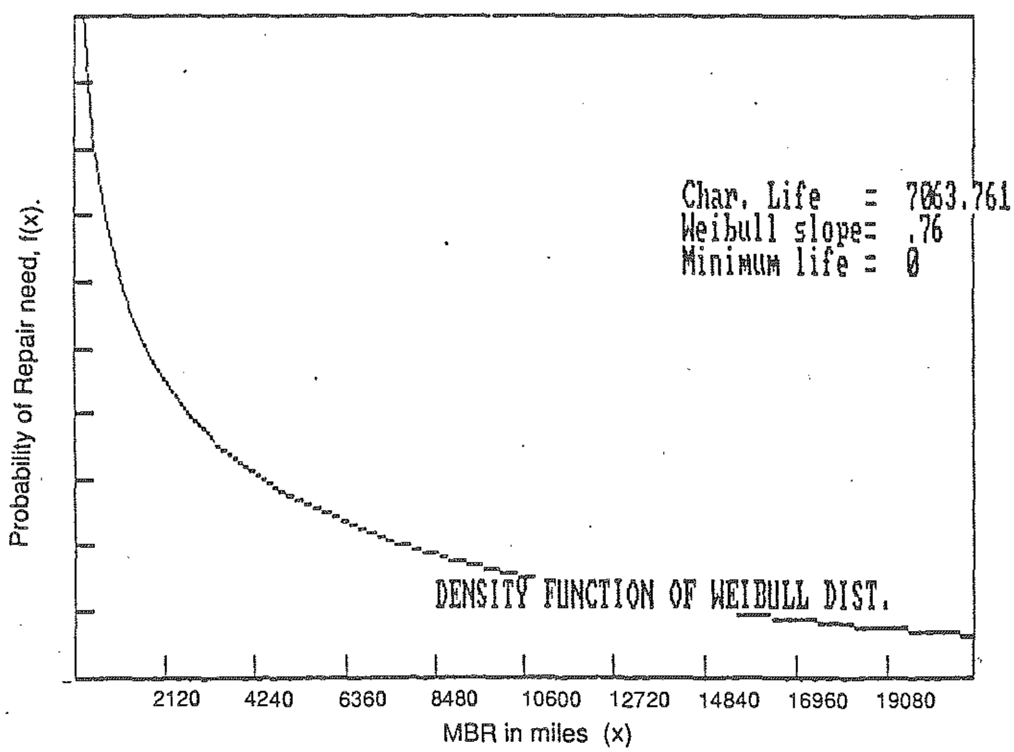


Figure-7(b). Weibull Density Function of MBR Distribution for Lift- A3

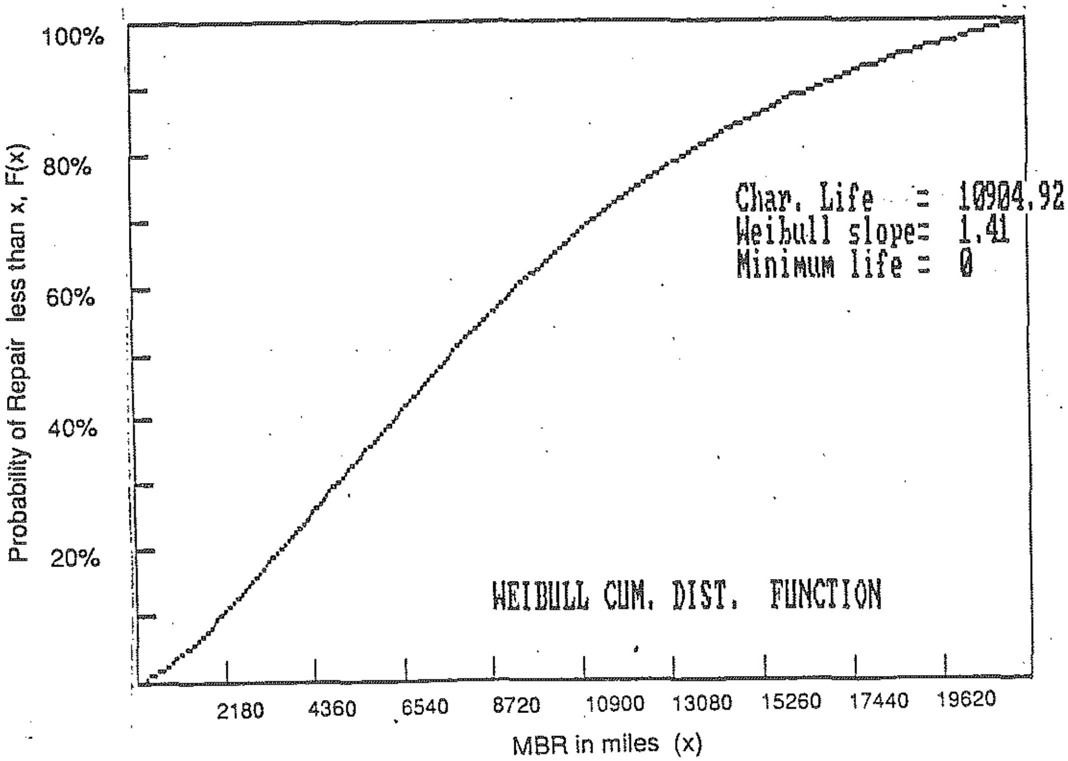


Figure-8(a). Weibull Cumulative MBR Distribution for Lift- A4

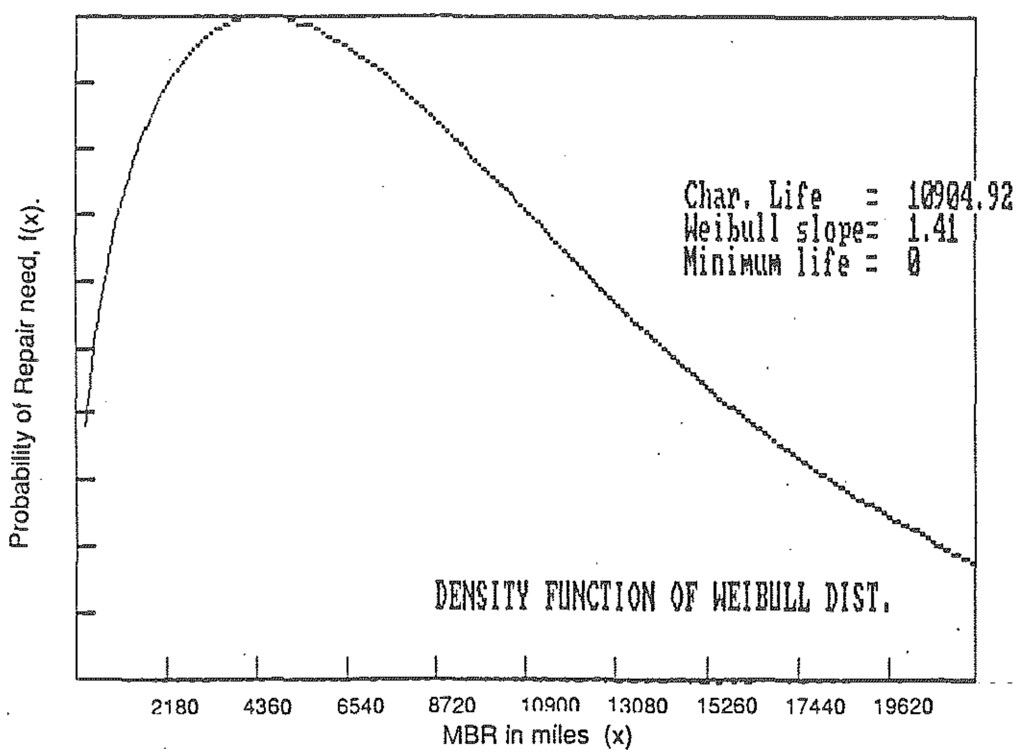


Figure-8(b). Weibull Density Function of MBR Distribution for Lift- A4

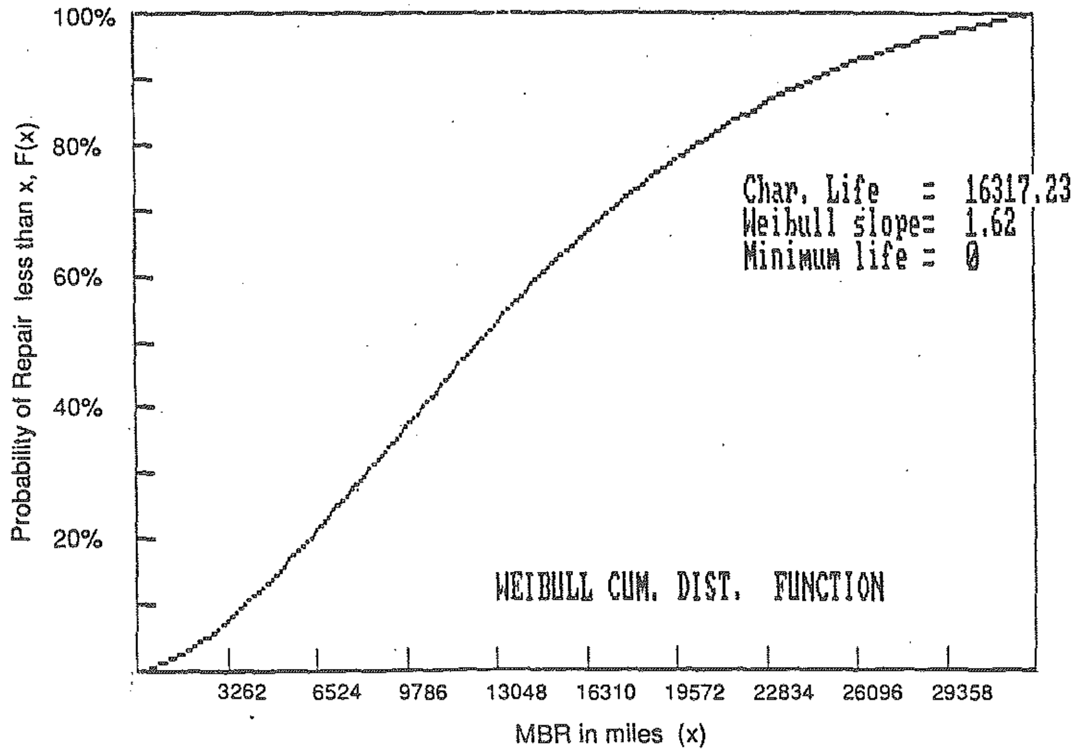


Figure-9(a). Weibull Cumulative MBR Distribution for Lift- A5

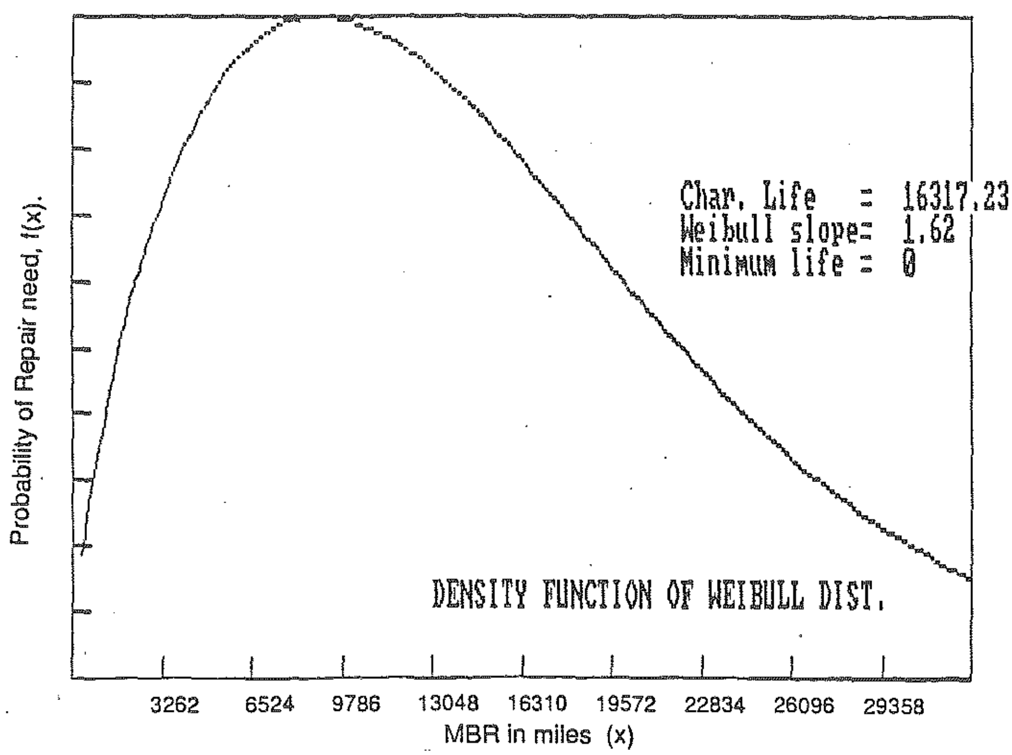


Figure-9(b). Weibull Density Function of MBR Distribution for Lift- A5

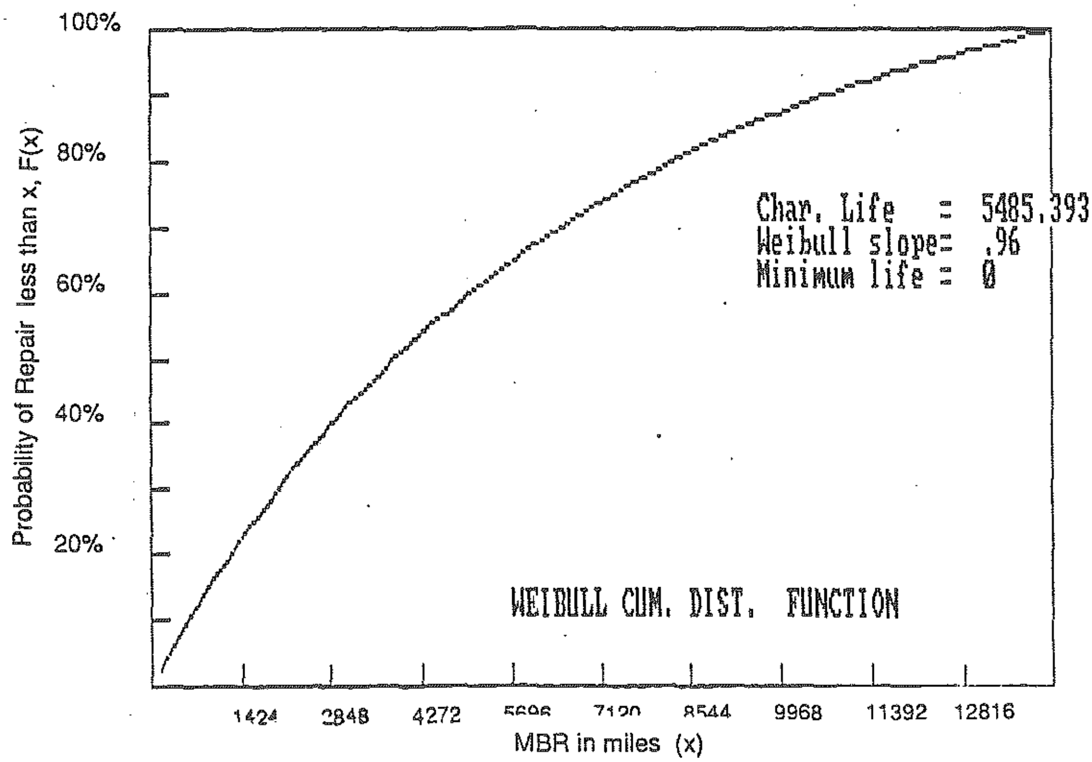


Figure-10(a). Weibull Cumulative MBR Distribution for Lift- B1

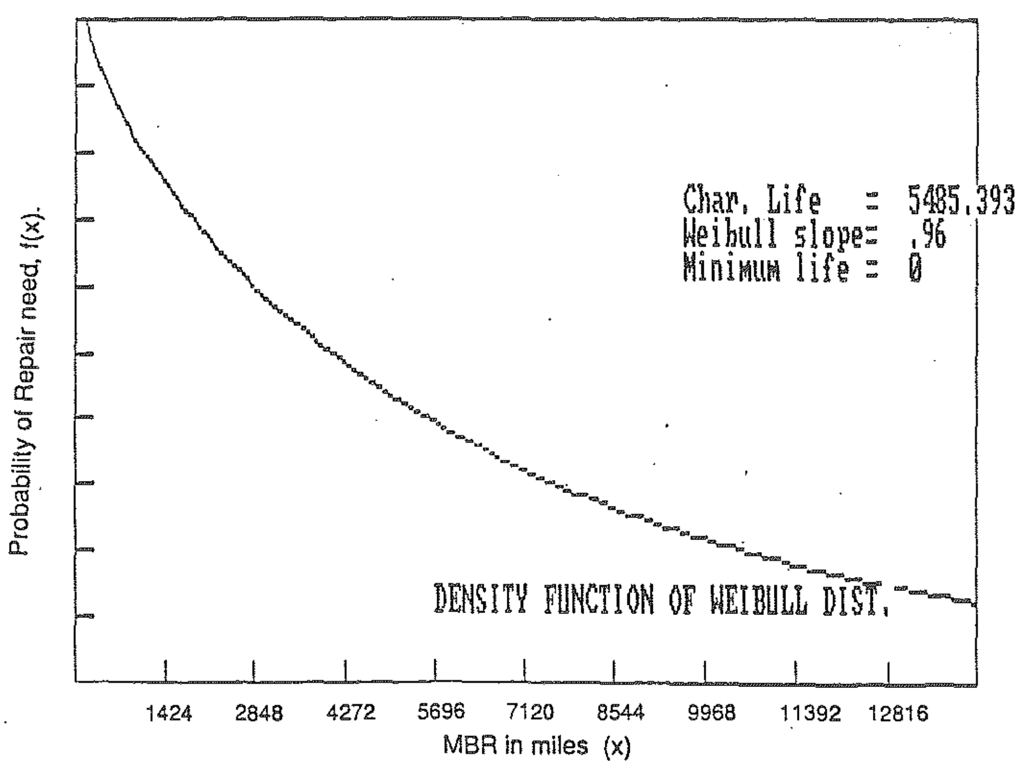


Figure-10(b). Weibull Density Function of MBR Distribution for Lift - B1

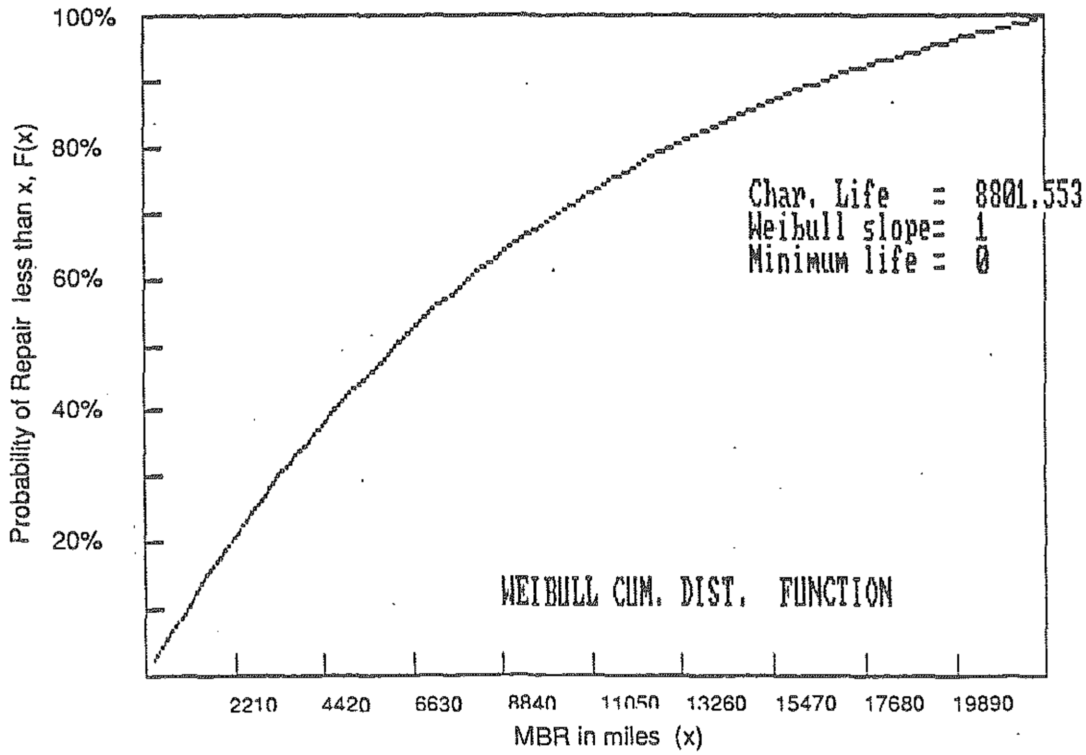


Figure-11(a). Weibull Cumulative MBR Distribution for Lift- B2

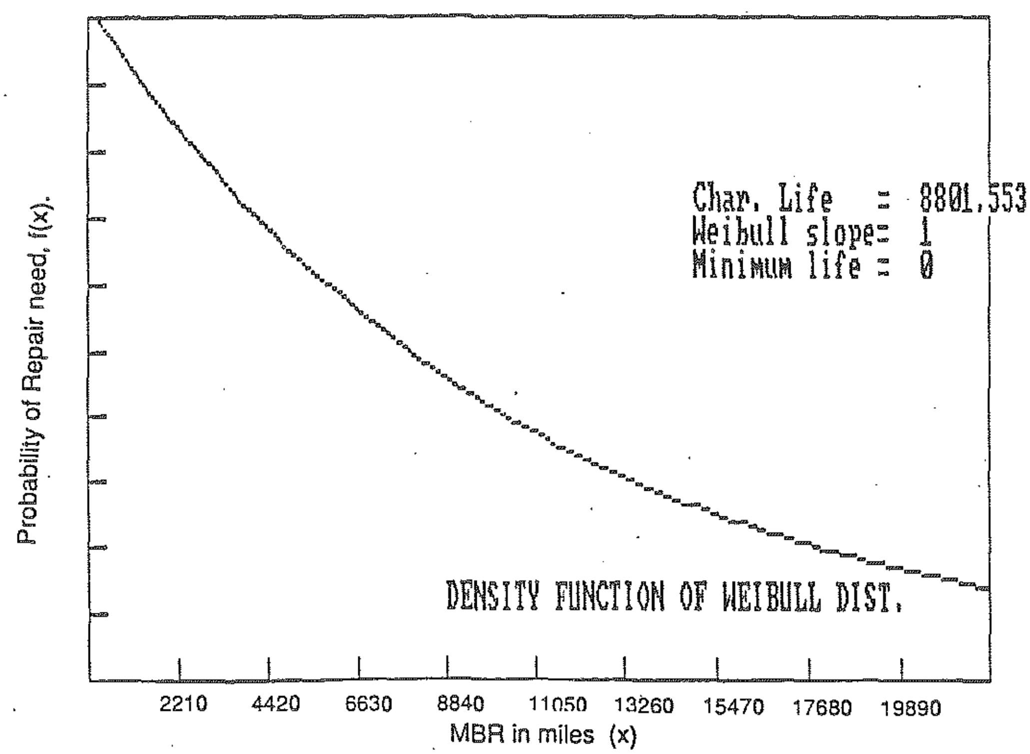


Figure-11(b). Weibull Density Function of MBR Distribution for Lift- B2

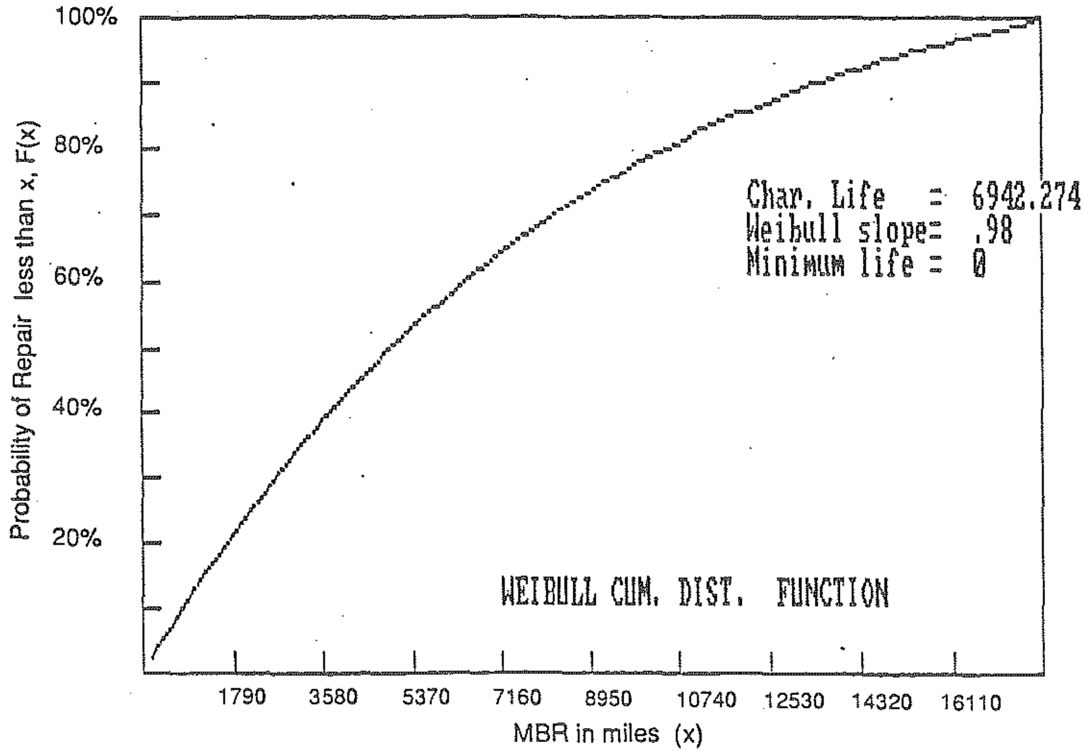


Figure-12(a). Weibull Cumulative MBR Distribution for Lift- B3

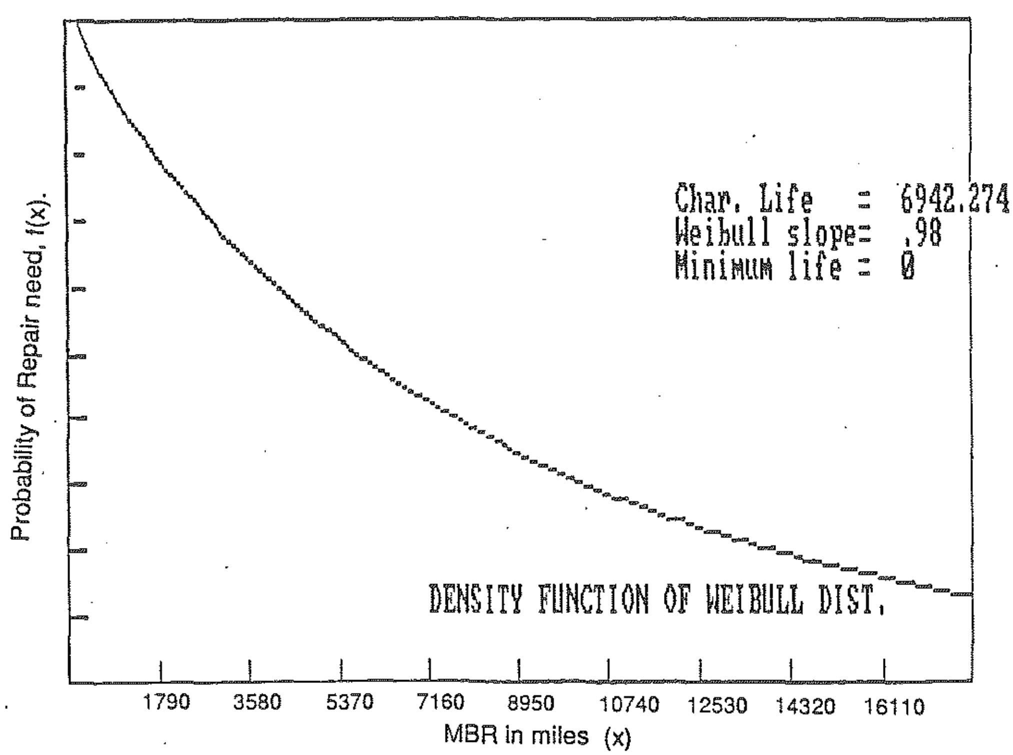


Figure-12(b). Weibull Density Function of MBR Distribution for Lift- B3

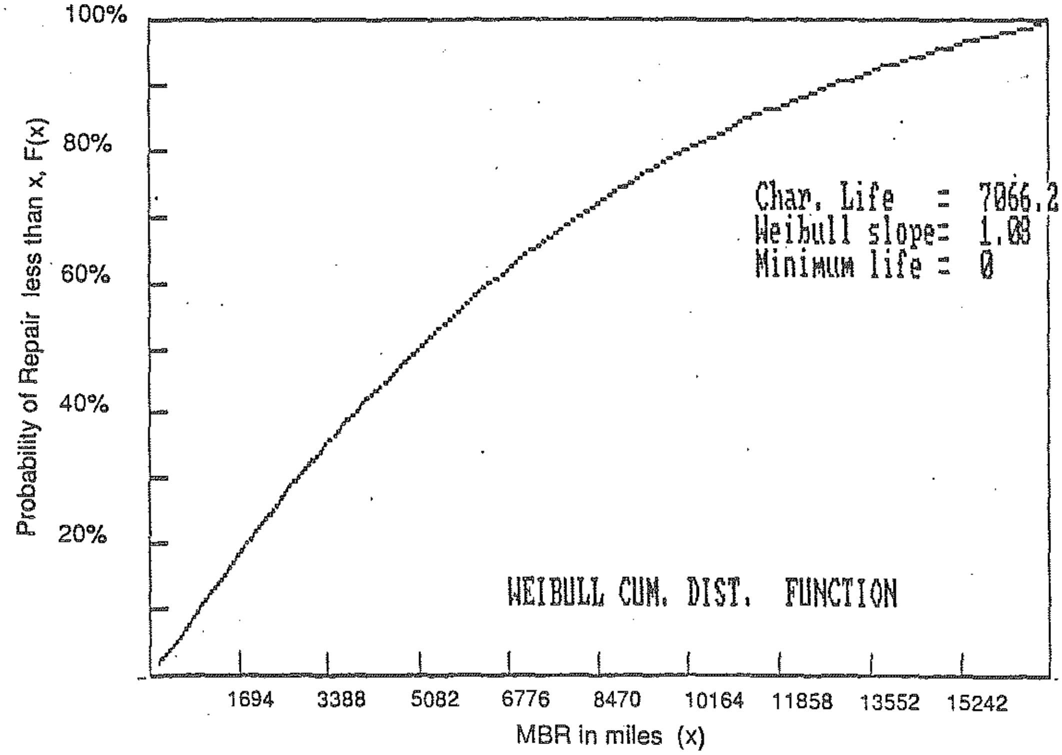


Figure-13(a). Weibull Cumulative MBR Distribution for Lift- B4

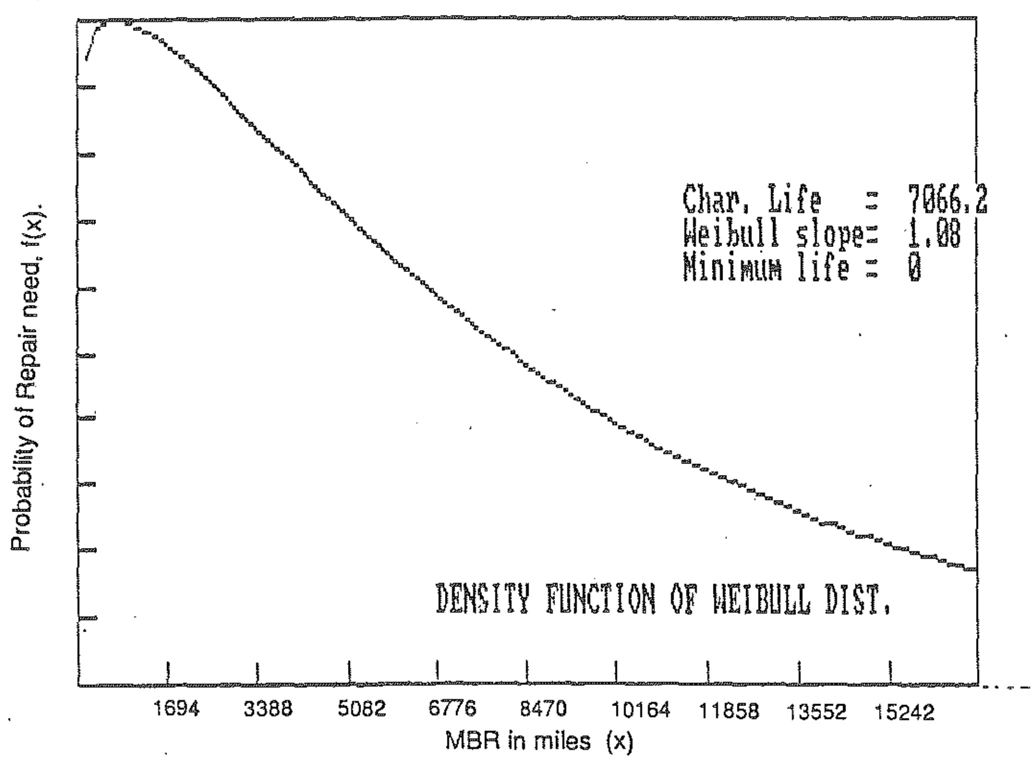


Figure-13(b). Weibull Density Function of MBR Distribution for Lift- B4

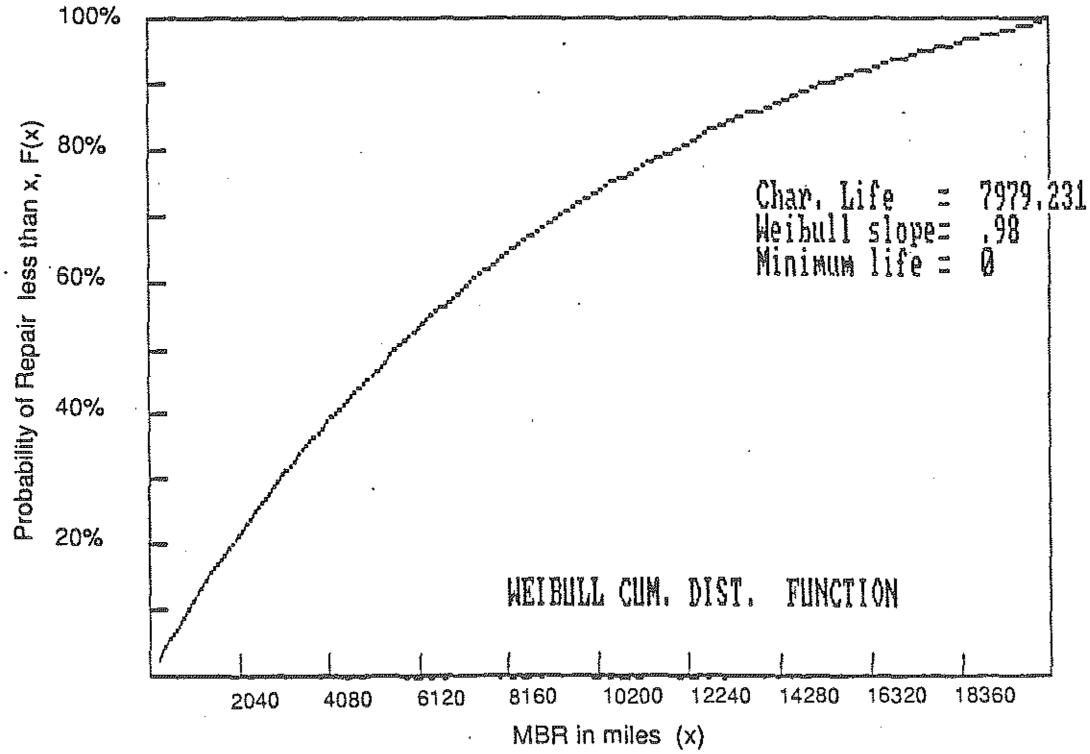


Figure-14(a). Weibull Cumulative MBR Distribution for Lift- B5

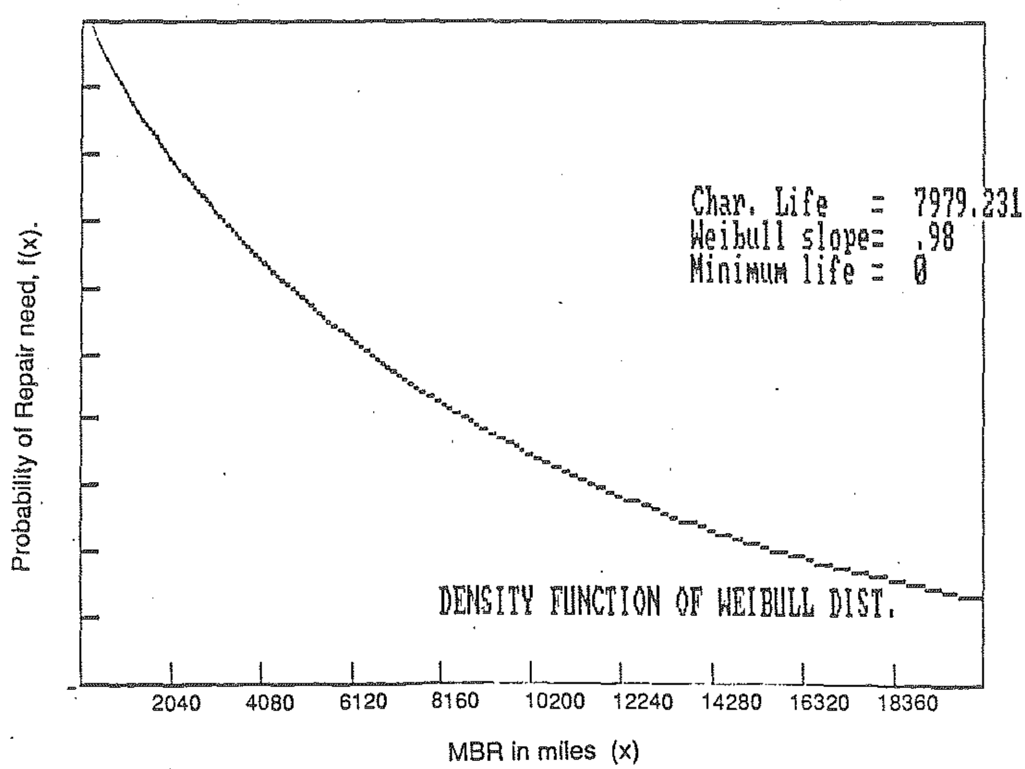


Figure-14(b). Weibull Density Function of MBR Distribution for Lift - B5

$$Y = \ln\ln\left(\frac{1}{1-F(x)}\right)$$

$$X = \ln X,$$

$$C = -b\ln\theta$$

So that $Y = bX + c$

Referring to Lift A1 from Table 8,

$b = 0.6505$

$c = -5.9961$

Since $\quad c = -b\ln\theta$

$$-5.9961 = -0.6505\ln\theta$$

$$\ln\theta = \left(\frac{-5.9961}{0.6505}\right) = 9.2176$$

So that

$\theta = e^{9.2176} = 10{,}073$

Note that the above value matches the calculated value of 10,075 as shown in Table-8.

4.3 Analysis of TBR Data:

Table 9 shows the Weibull parameters for TBR distribution for the same 10 lifts (5 for Type A and 5 for Type B). These tables can be interpreted the same way as already explained for the MBR distribution in preceding section. As is the case of the MBR distribution, characteristic life for the TBR distribution, as measured by the θ value (63% percentile value of the time elapsed in months between successive

Table-9. Weibull Parameters for TBR Distribution

Lift type & number	R**2 correlation coefficient	O characterstic life in months	b slope	N	Equation Y=bX +c*
A-1	0.956042	2.08926	0.700	19	y=0.70X - 0.5191
A-2	0:848980	2.45072	1.060	23	y=1.06X -0.9565
A-3	0.963278	1.67867	0.820	30	y=0.82X -0.4282
A-4	0.973360	2.40805	1.110	25	y=1.11X -0.9774
A-5	0.958320	3.44458	1.180	17	y=1.18X -1.4659
Average		2.41430	0.974		
B-1	0.9773260	1.55440	0.758	49	y=0.76X -0.4791
B-2	0.9377720	1.86181	1.050	33	y=1.06X -0.6562
B-3	0.9837175	1.35523	0.960	42	y=0.96X -0.2948
B-4	0.9498300	1.39313	1.170	40	y=1.17X -0.3899
B-5	0.9826970	1.57874	1.160	41	y=1.16X -0.5310
Average		1.56270	0.955		

* y= ln ln (1./1-F(x)).
x= ln(x).
c= -b ln(0).

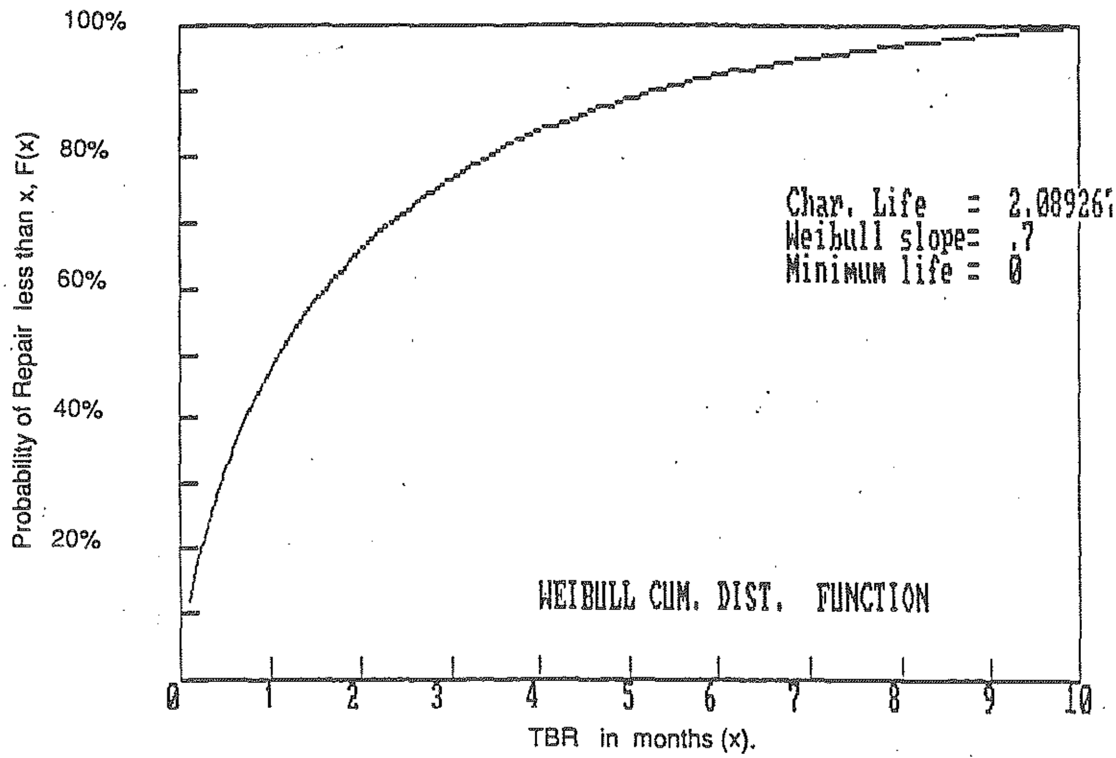


Figure-15(a). Weibull Cumulative TBR Distribution for Lift- A1

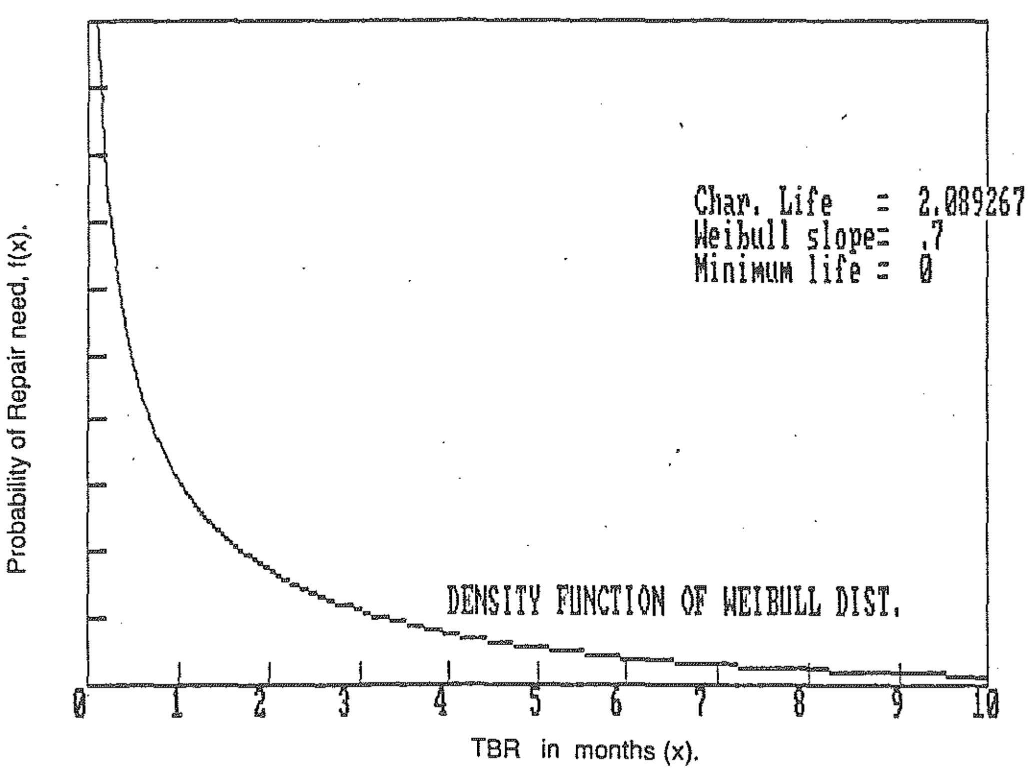


Figure-15(b). Weibull Density Function of TBR Distribution for Lift - A1

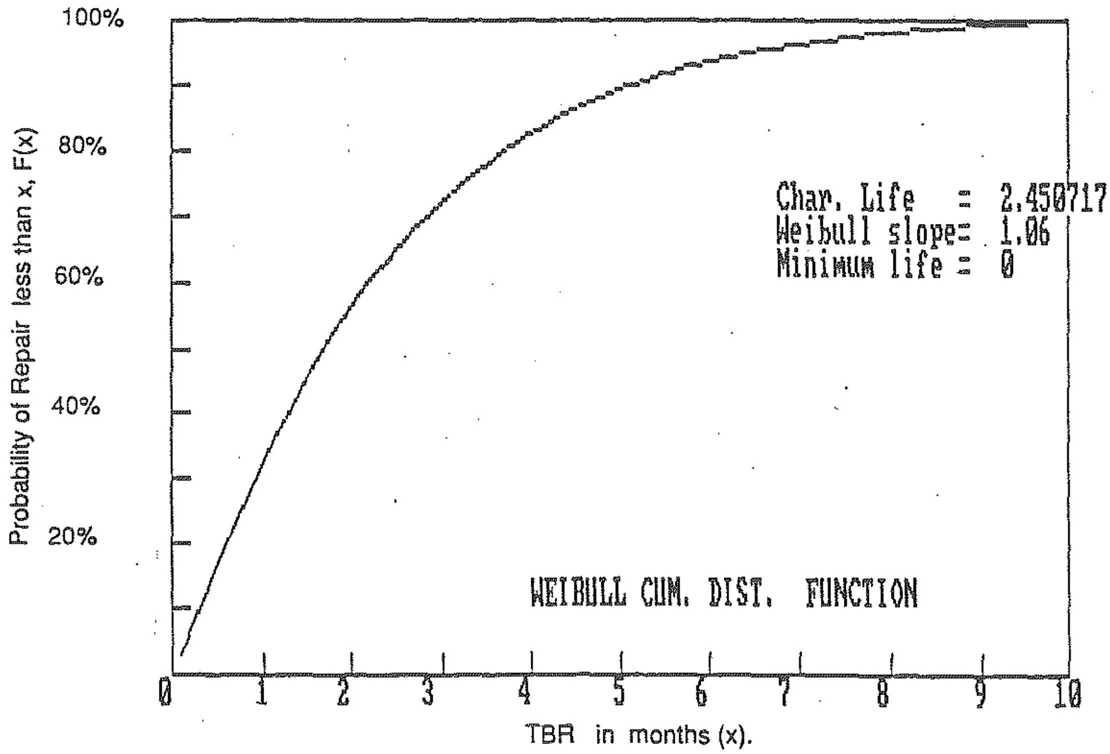


Figure-16(a). Weibull Cumulative TBR Distribution for Lift- A2

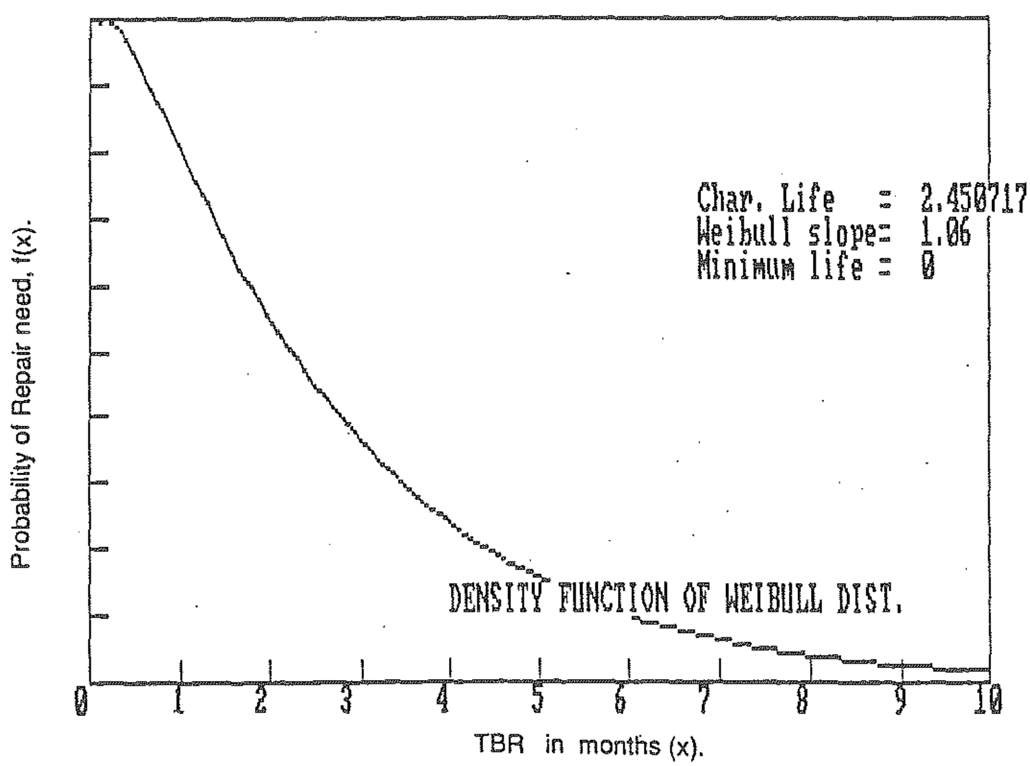


Figure-16(b). Weibull Density Function of TBR Distribution for Lift- A2

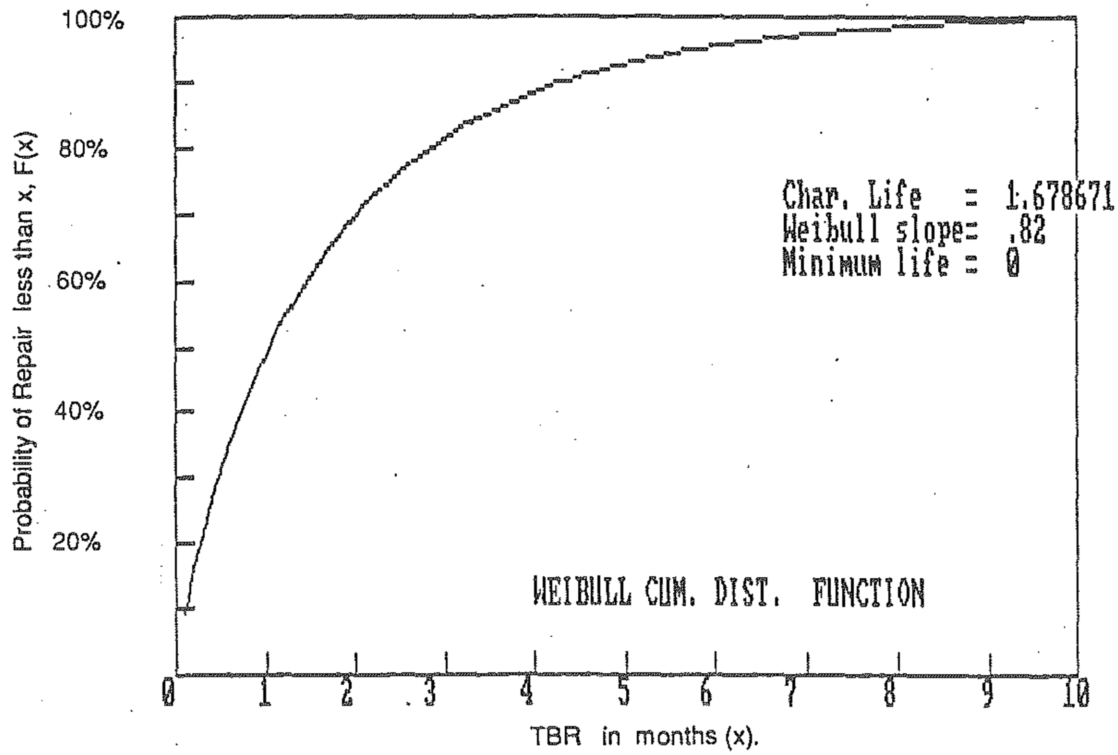


Figure-17(a). Weibull Cumulative TBR Distribution for Lift- A3

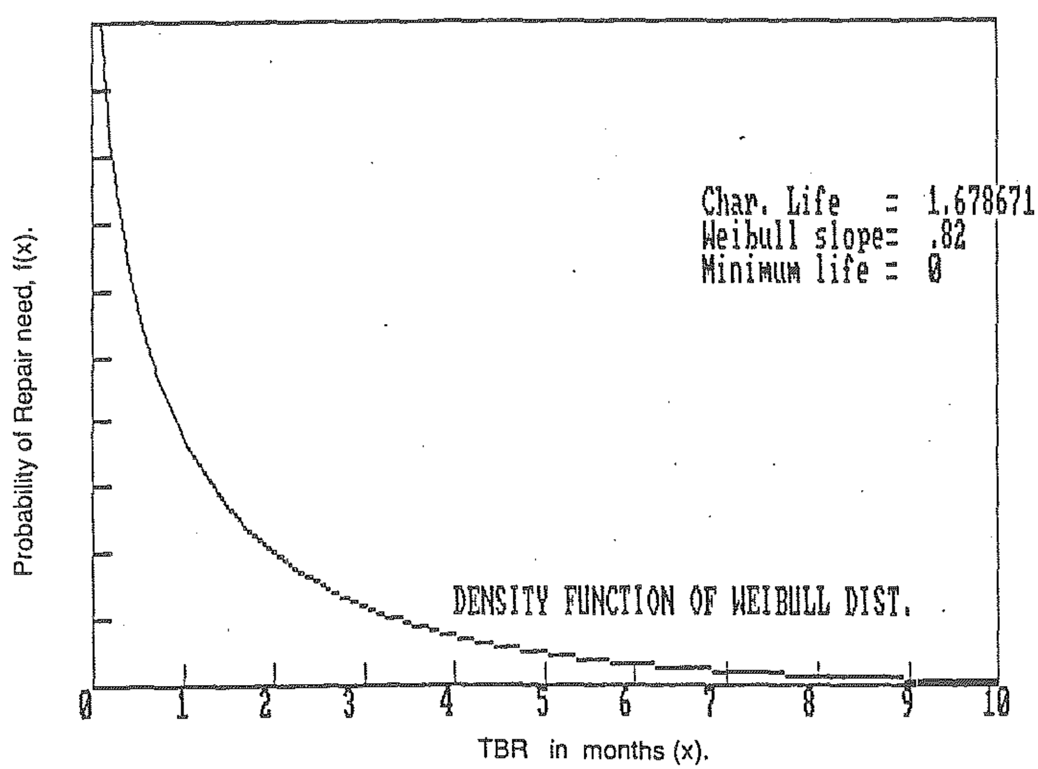


Figure-17(b). Weibull Density Function of TBR Distribution for Lift- A3

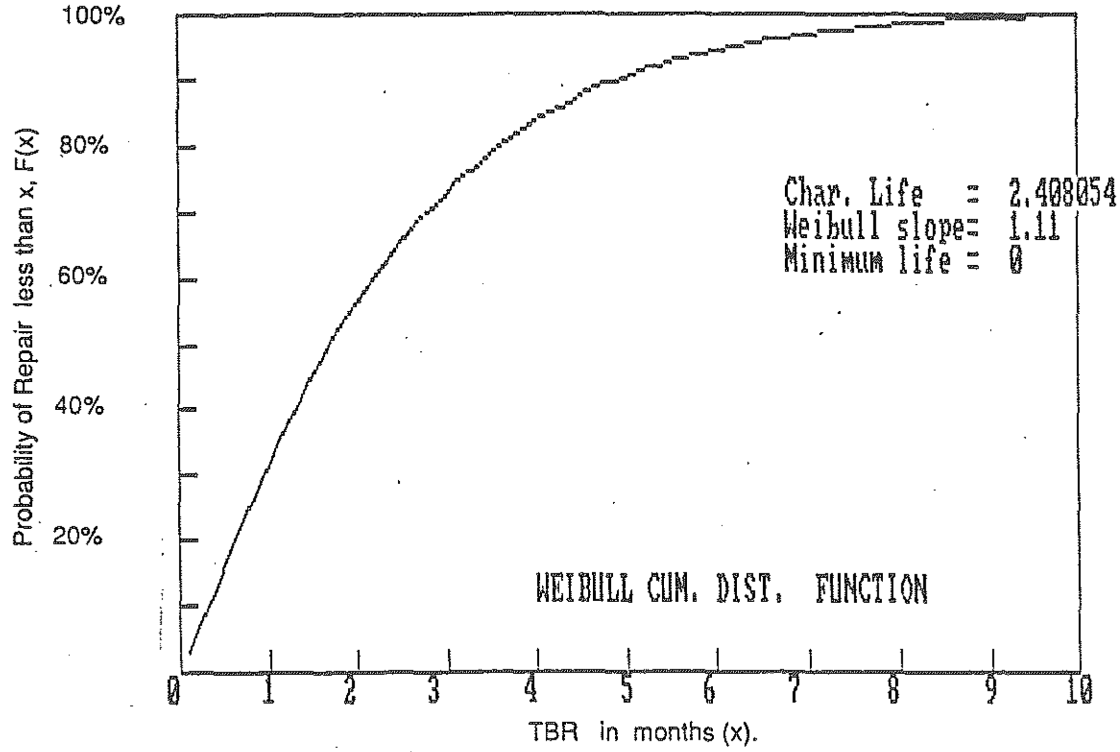


Figure-18(a). Weibull Cumulative TBR Distribution for Lift- A4

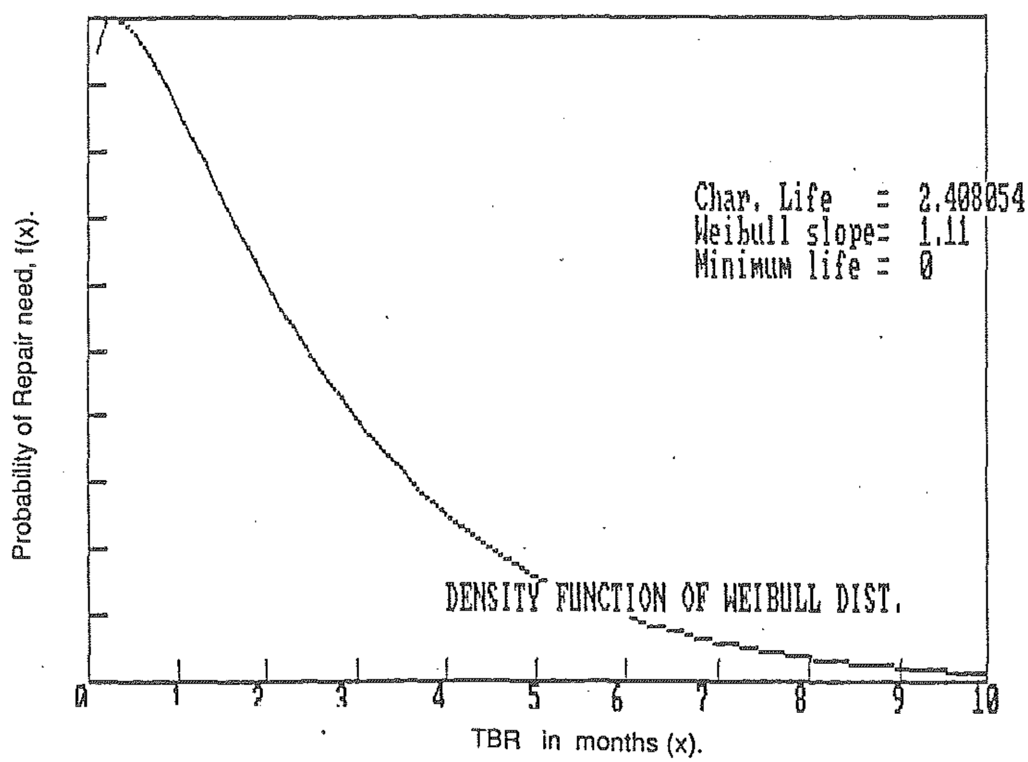


Figure-18(b). Weibull Density Function of TBR Distribution for Lift- A4

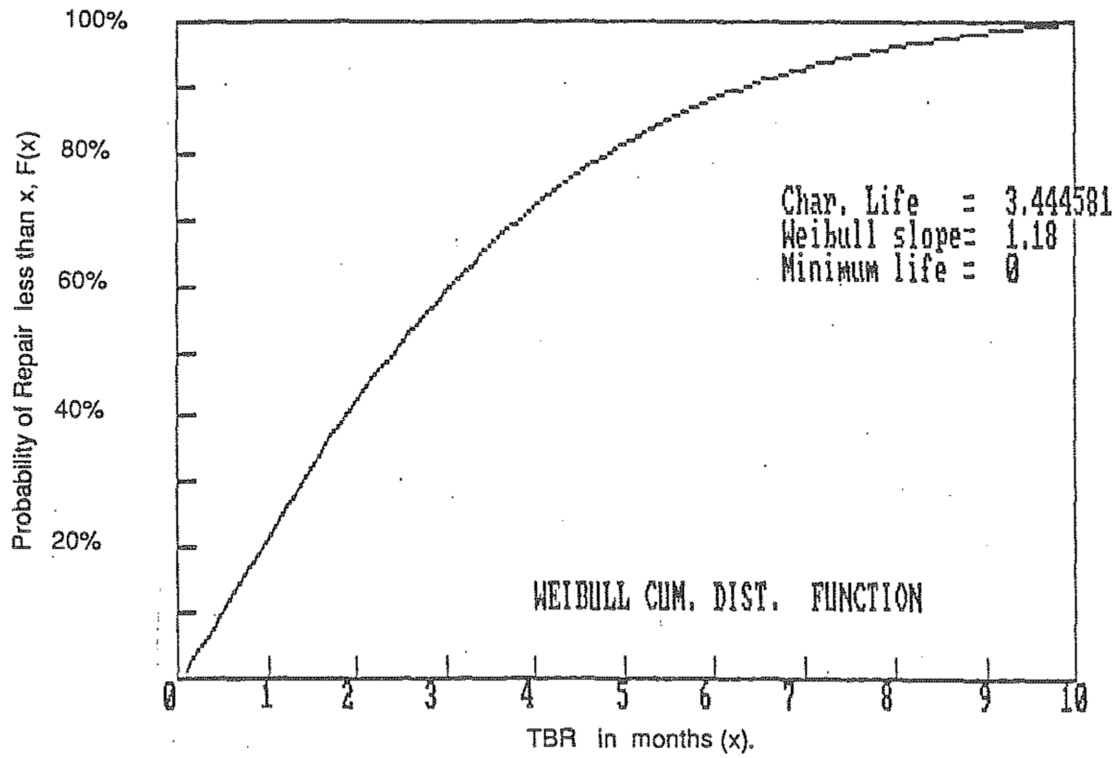


Figure-19(a). Weibull Cumulative TBR Distribution for Lift- A5

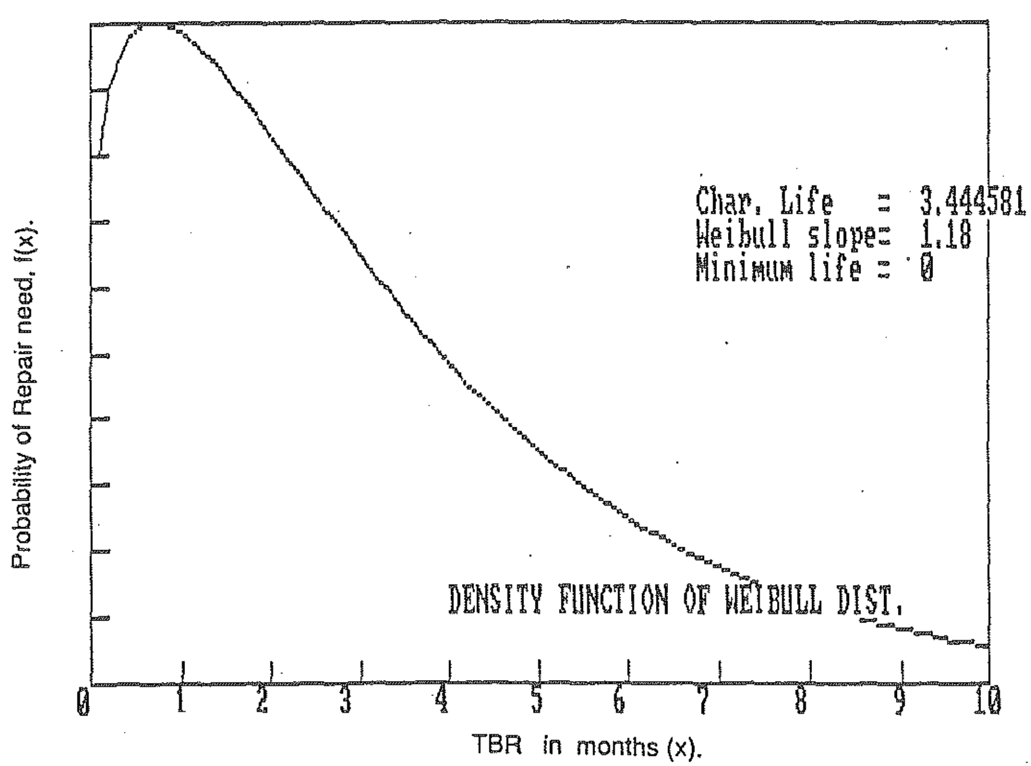


Figure-19(b). Weibull Density Function of TBR Distribution for Lift - A5

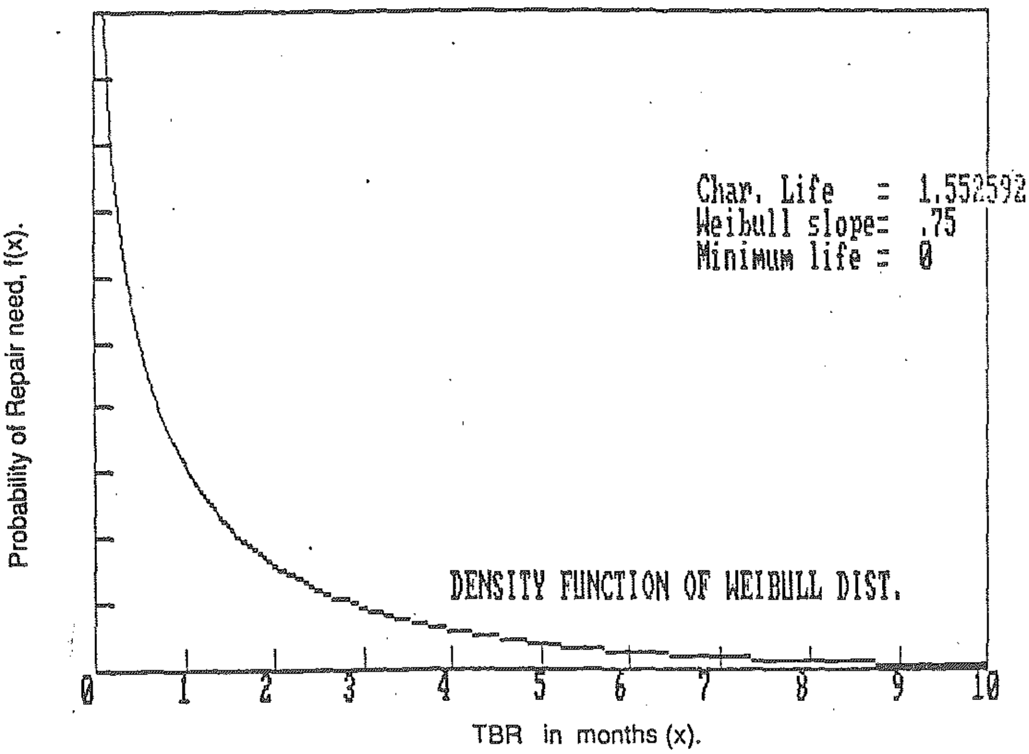


Figure-20(a). Weibull Density Function of TBR Distribution for Lift-B1.

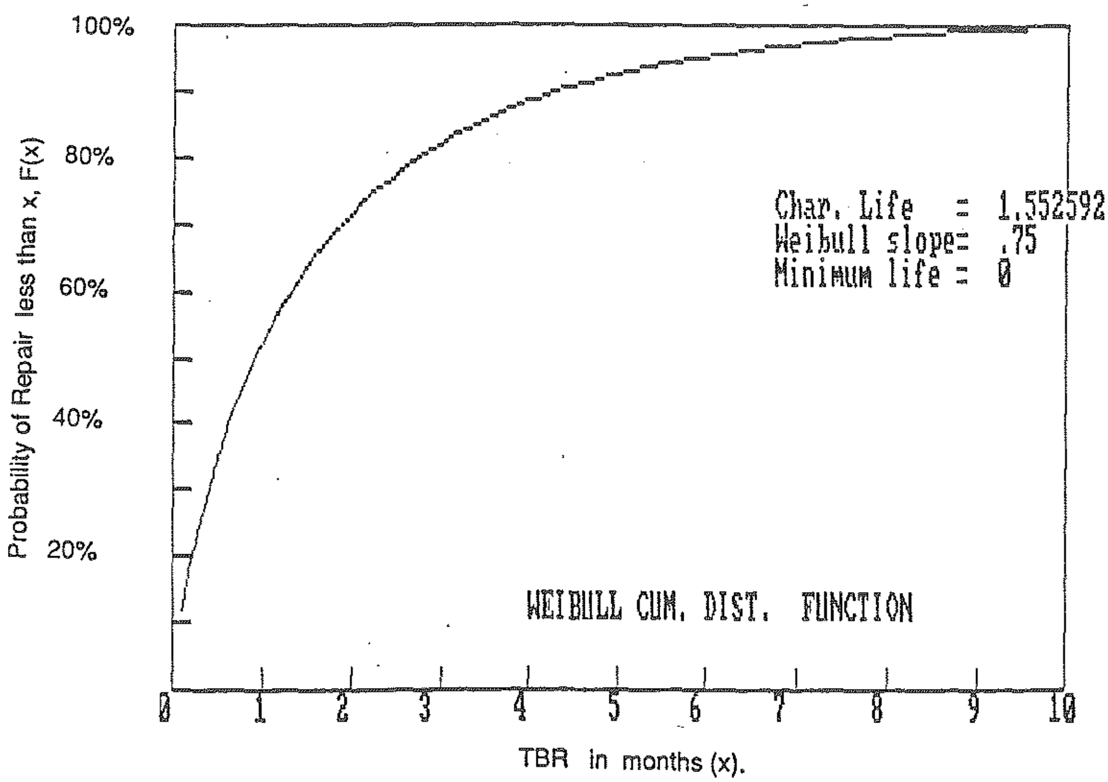


Figure-20(b). Weibull Cumulative TBR Distribution for Lift-B1.

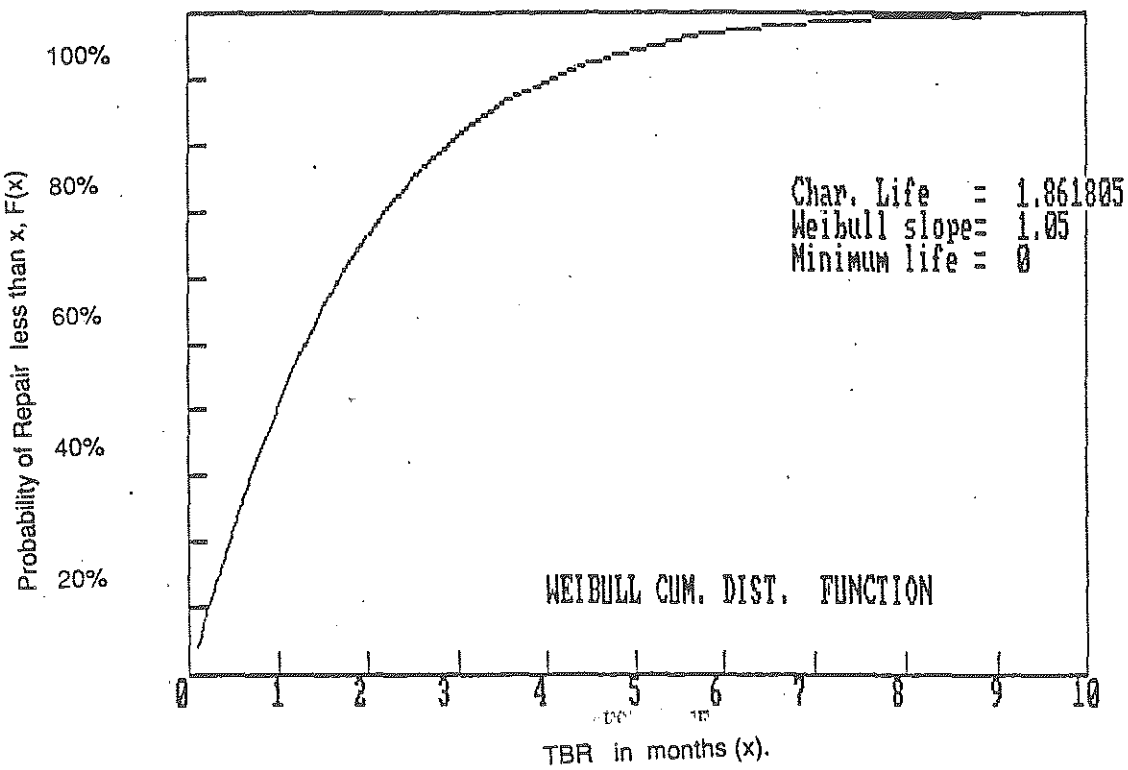


Figure-21(a). Weibull Cumulative TBR Distribution for Lift- B2

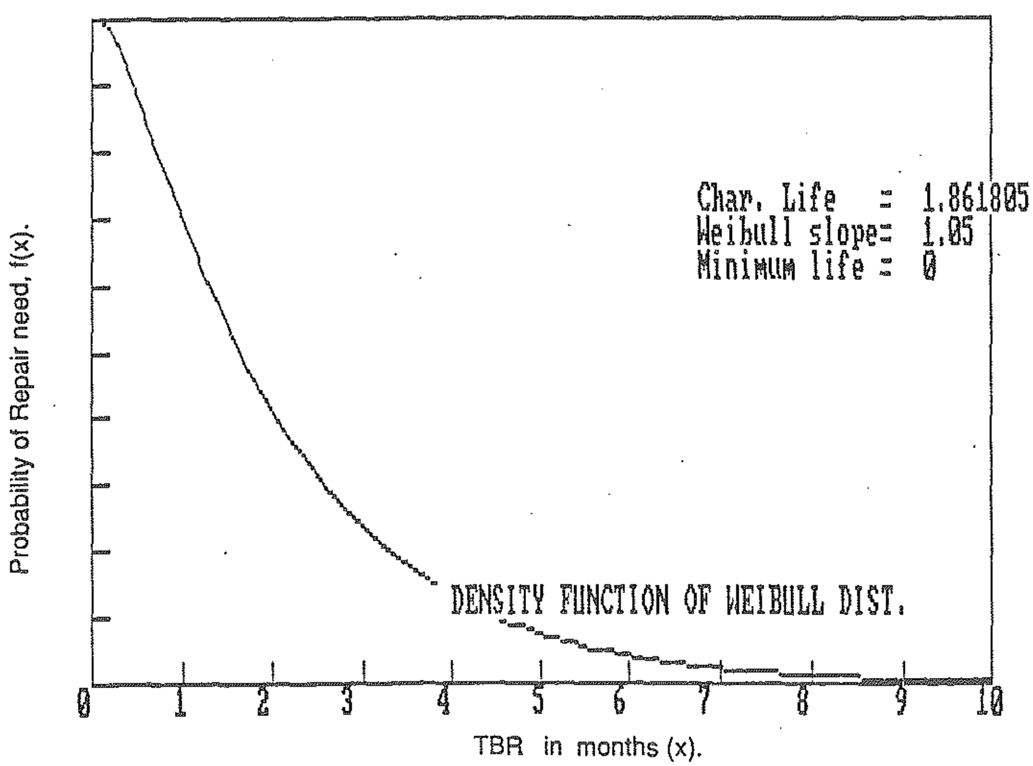


Figure-21(b). Weibull Density Function of TBR Distribution for Lift - B2

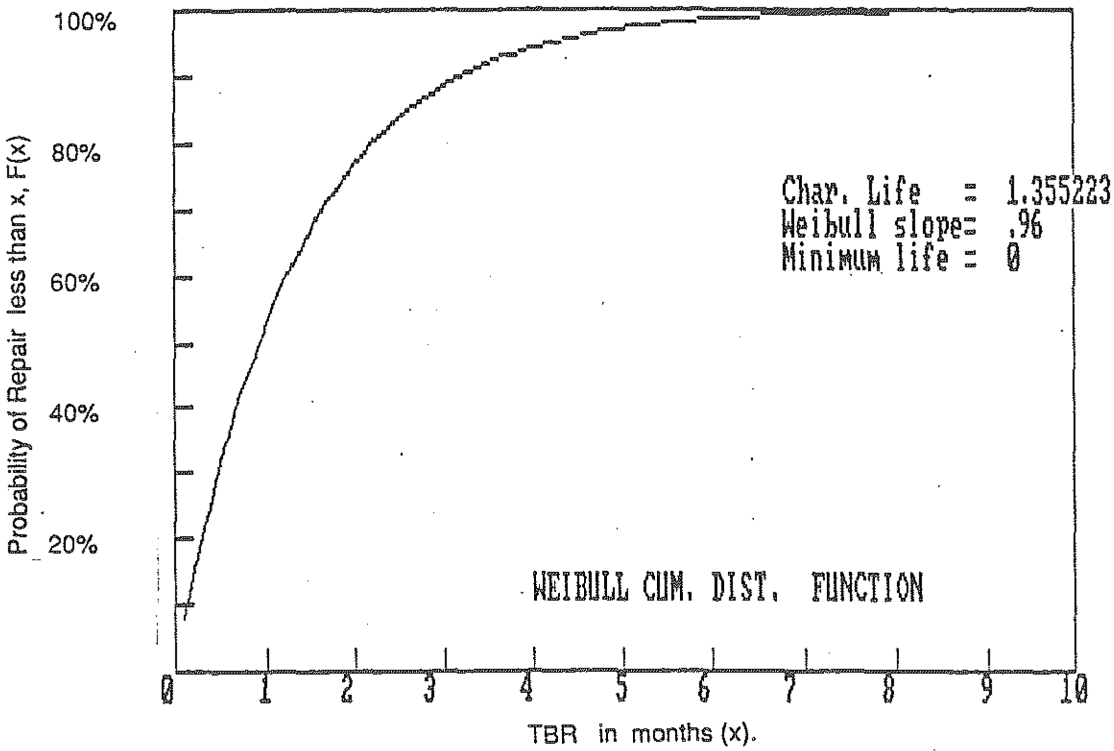


Figure-22(a). Weibull Cumulative TBR Distribution for Lift- B3

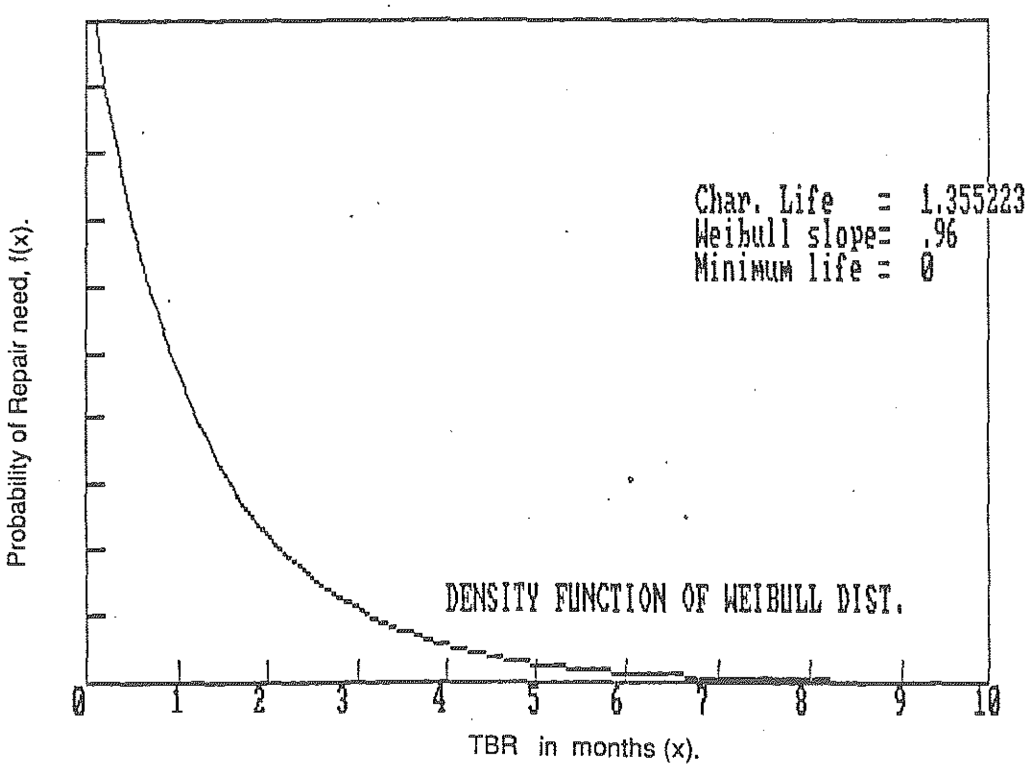


Figure-22(b). Weibull Density Function of TBR Distribution for Lift - B3

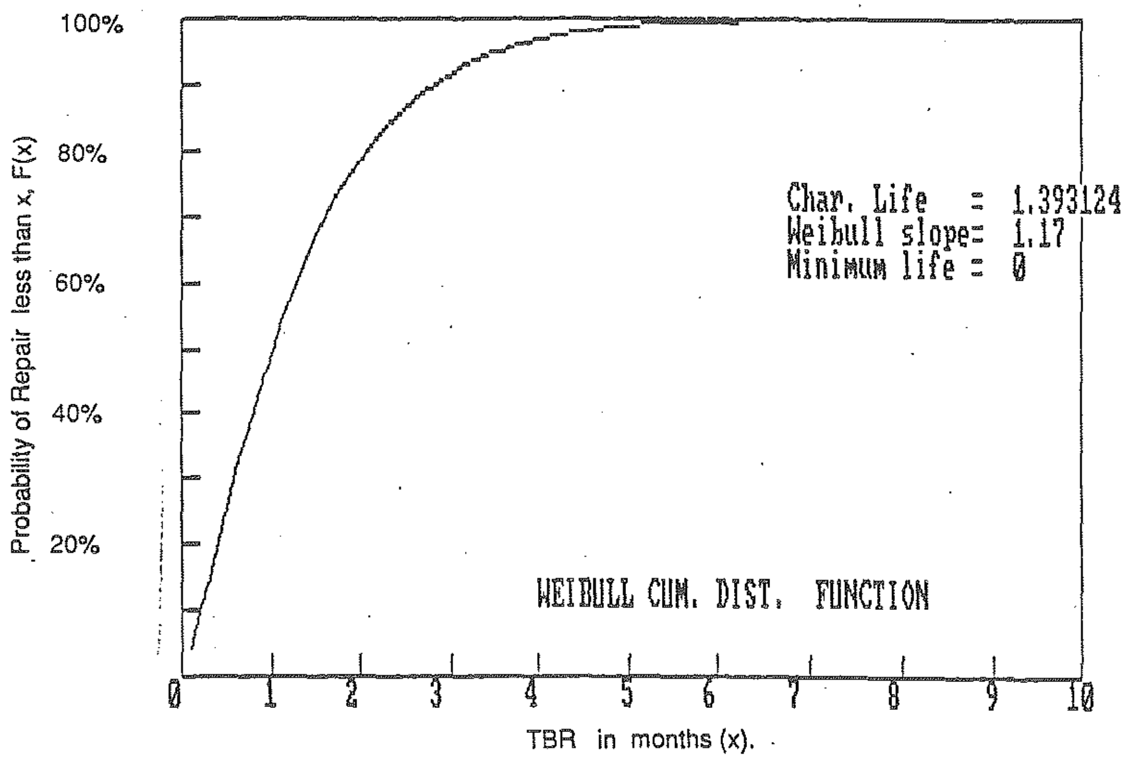
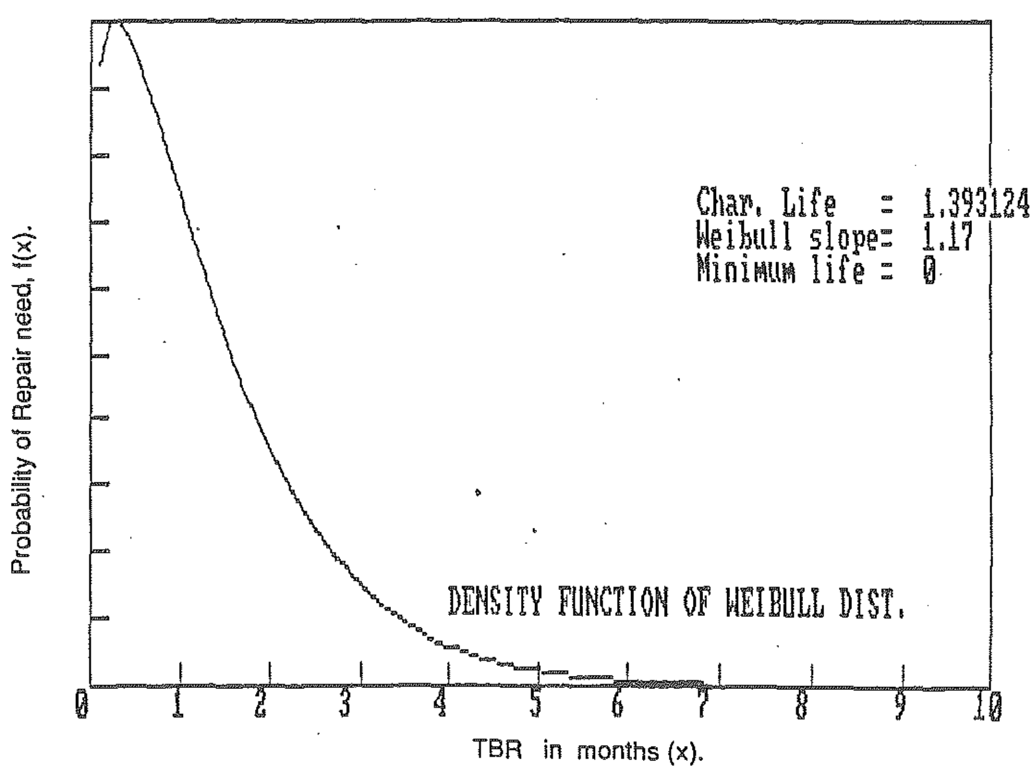


Figure-23(a). Weibull Cumulative TBR Distribution for Lift- B4



Fiqure-23(b). Weibull Density Function of TBR Distribution for Lift - B4

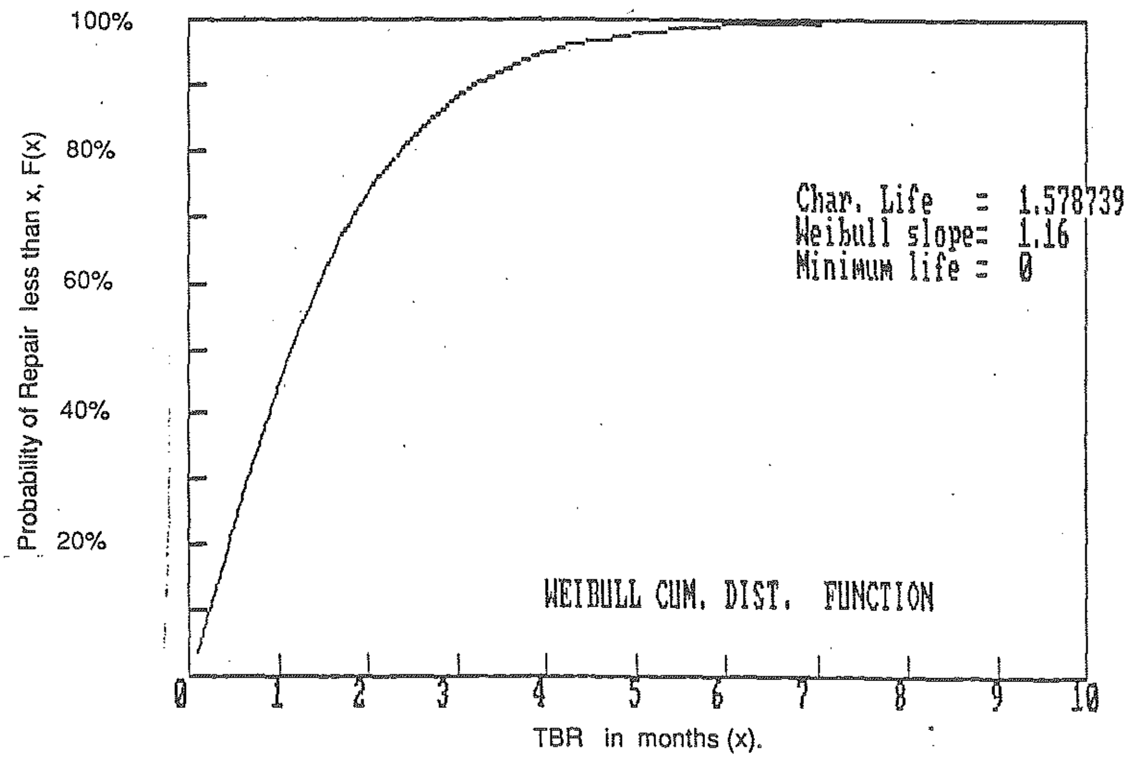


Figure-24(a). Weibull Cumulative TBR Distribution for Lift- B5

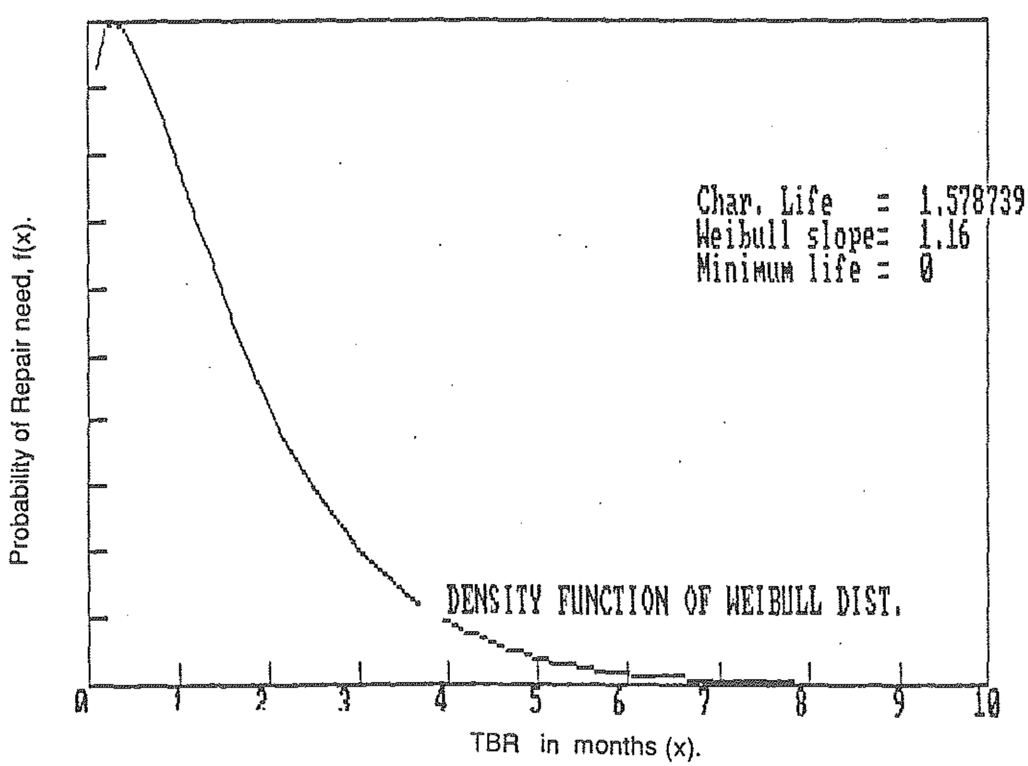


Figure-24(b). Weibull Density Function of TBR Distribution for Lift - B5

repairs) is higher for Type A lifts than Type B. This would seem to further support the idea that Type A lifts longevity is higher than Type B. However, the validity of this conclusion can be questioned because the cost of repair was not included in the analysis. The following specific observation on the TRB Weibull function can be noted:

(1) The consistency in the θ-values within the same type of lift is worth noting, notwithstanding the difference between lift Type A and B. For lift Type A, the composite average θ is 2.4143, indicating that 63% of times, for Type A lift, a repair is likely to be warranted within 2.414 months. The corresponding figure for Type B lift is 1.56270.

(2) The slope parameter b for TBR distribution is close to unity, with 4 out of the 10 observations being less than one and the remaining values exceeding one.

(3) Figure 15 through 24 show the f(x) and F(x) values for TBR distribution, as done for MBR distribution in Figure 5 through 14. In all the ten cases analyzed, the characteristic life θ computed by the model approximates the 63 percentile value of the CDF curve. For example, in Figure 15, the 63 percentile value is 2.0, compared to the θ value of 2.089 computed by the model. The patterns of the CDF curves are monotonic for b-values less than unity. For b-values exceeding unity, the peak of the CDF is attained at a point slightly to the right of the origin. The above pattern matches the theoritical distribution of Weibull curves discussed earlier.

5. STRUCTURAL ANALYSIS

5.1 Introduction:

The purpose of the structural analysis is to investigate the rigid platform wheelchair lift structural system serviceability and strength. The primary objective is to evaluate if there are any over-stresses or excessive deformations of the lift structural system as to cause any reliability related problems with repeated lift operation. The secondary objective is to analyze the lift under operating loads to evaluate if deformations exceed the human comfort levels as set by the serviceability requirements. Serviceability related problems were observed during initial field investigations on the prototype rigid platform lifts.

There are three major suppliers of rigid platform lifts for that are typically procured by the MDOT. For the purpose of this study the structural model properties are based on the product of one manufacturer. However, the lift structural system of the three manufacturers are very similar for analysis purposes, and the structural model can be utilized for the analysis of other lifts with minor geometric and component property modifications. There is a major difference in the lift operation that affects the demands on the structural system. The load demands change based on whether the lift deployment is automatic or "gravity down". For the purposes of this analysis lift automatic deployment is selected.

5.2 Review of Rigid Platform Lift Structural Specifications:

The specifications pertaining to the lift structural system is covered in three documents [1, 9, 10.] These are grouped under design loads for service and ultimate limit states, allowable and maximum component stress, allowable deformations, testing and durability requirements. The most comprehensive specification covering the above aspects is the UMTA document which is the primary basis of the manufacturers design specifications [10].

The critical aspects of the lift structural system are summarizes as follows based on ref, [10]:

Lift system self weight is limited to 1000 pounds for standard buses and 400 pounds for small buses.

Service (operating) design load is 600 pounds and ultimate design load is 1800 pounds. Ultimate design load is defined as the load to initiate yielding in any component.

Lift service deformations are defined in terms of platform rotations and limited to 3^0 in any direction.

The dynamic actions during lift operation are defined in terms of platform dynamics and limited to a maximum of 6 inches/second velocity, 0.3g acceleration and 0.3g/second jerk.

Lift durability is defined in two forms: useful life of 12 years and cycles of operation. The durability in terms of operating cycles is described in durability tests as 10,000 cycles of deployment, 600 cycles operation under 600 pounds followed by 15,000 cycles under 400 pounds.

5.3 Geometric Properties of the Lift Structural System:

The rigid platform lift structural system consists of three main subassemblages: (1) the frame for the connection to the bus structure, (2) is the deployment substructure, and (3) the platform frame.The geometric properties of the deployment system and the platform system are defined by the functional expectations from the lift and constraints imposed by the bus size. More specifically, that is the wheelchair size that can be accommodated is a function of the platform

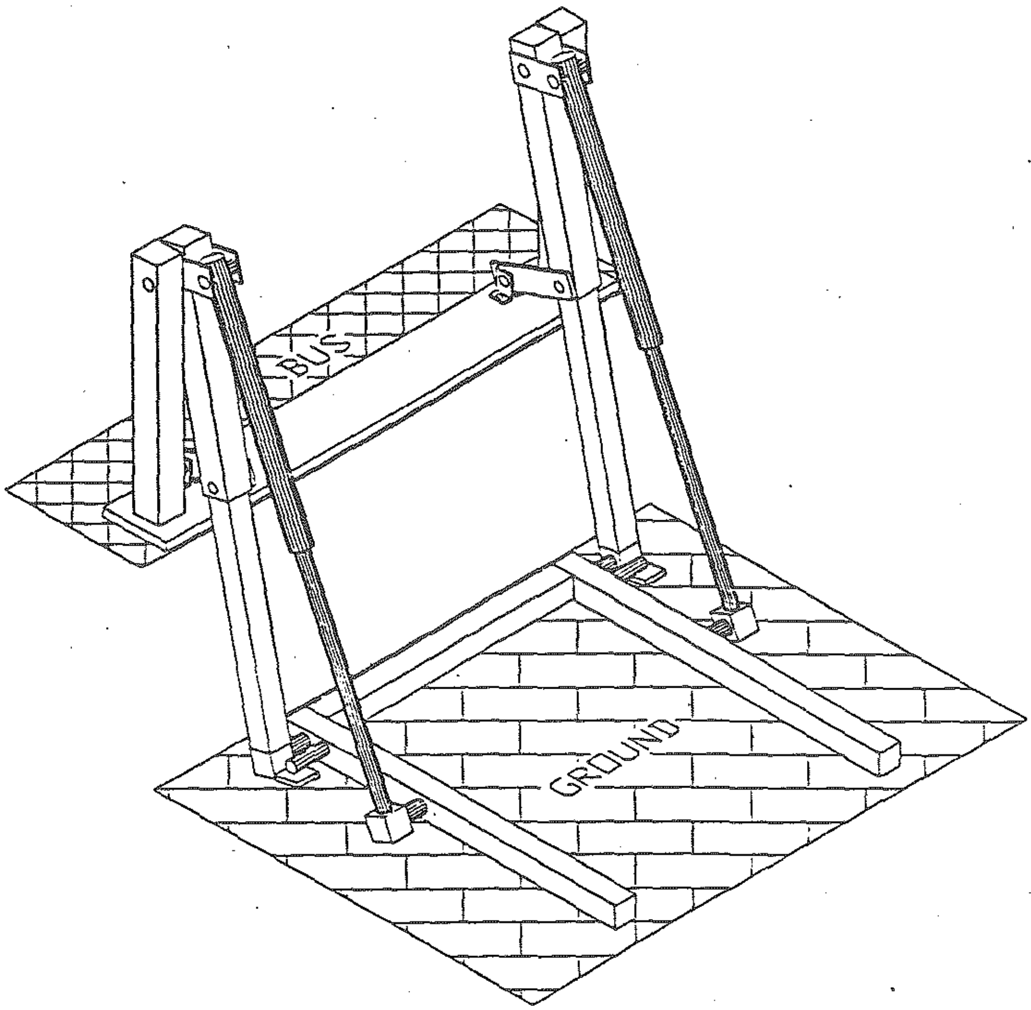


Figure-25. A Rigid Platform Lift in Deployed position.

size, and deployment system geometry is related to the bus floor clearance from ground. The rigid platform lifts that require a deployment distance of approximately 45 inches and, the platform dimensions vary between different manufacturers and models. In this study a typical platform dimensions of 30 inches wide and 42 inches long is used.

The rigid platform lift used as the example in this report is shown in figure 26 in the semi-deployed position. To move the lift for full deployment the dual hydraulic cylinders extend downward approximately 45" or until contact is made with the ground surface. To move the lift to stow away position the hydraulic cylinders this time will retract and fold the platform in between the sliding tube assembly upon which the cylinder and sliding tube assembly will swing inwards and align with the main frame connected to the bus structure. Thus, the platform dimensions and travel length controls overall lengths of the lift structure components. During deployment a bridge plate joins the platform with the bus floor and the platform is held at semi-deployed position with two key-hinges one at each end that allows only 90 degree rotation of the platform.

The simplified geometric description of the lift structure is shown in figure 25. In this figure, only the components that are contribute to the lift load carrying capacity are retained. The structural components that are not included in figure 25 are the bridge plate, platform decking and the hand rail. In addition, the key-hinge connections that hold the platform rigidly in deployed position are simplified.

5.4 Finite Element Model:

The finite element model of the lift structural system is developed from the simplified geometry shown on figure 26. The figure 26 also includes node numbers which designate the element

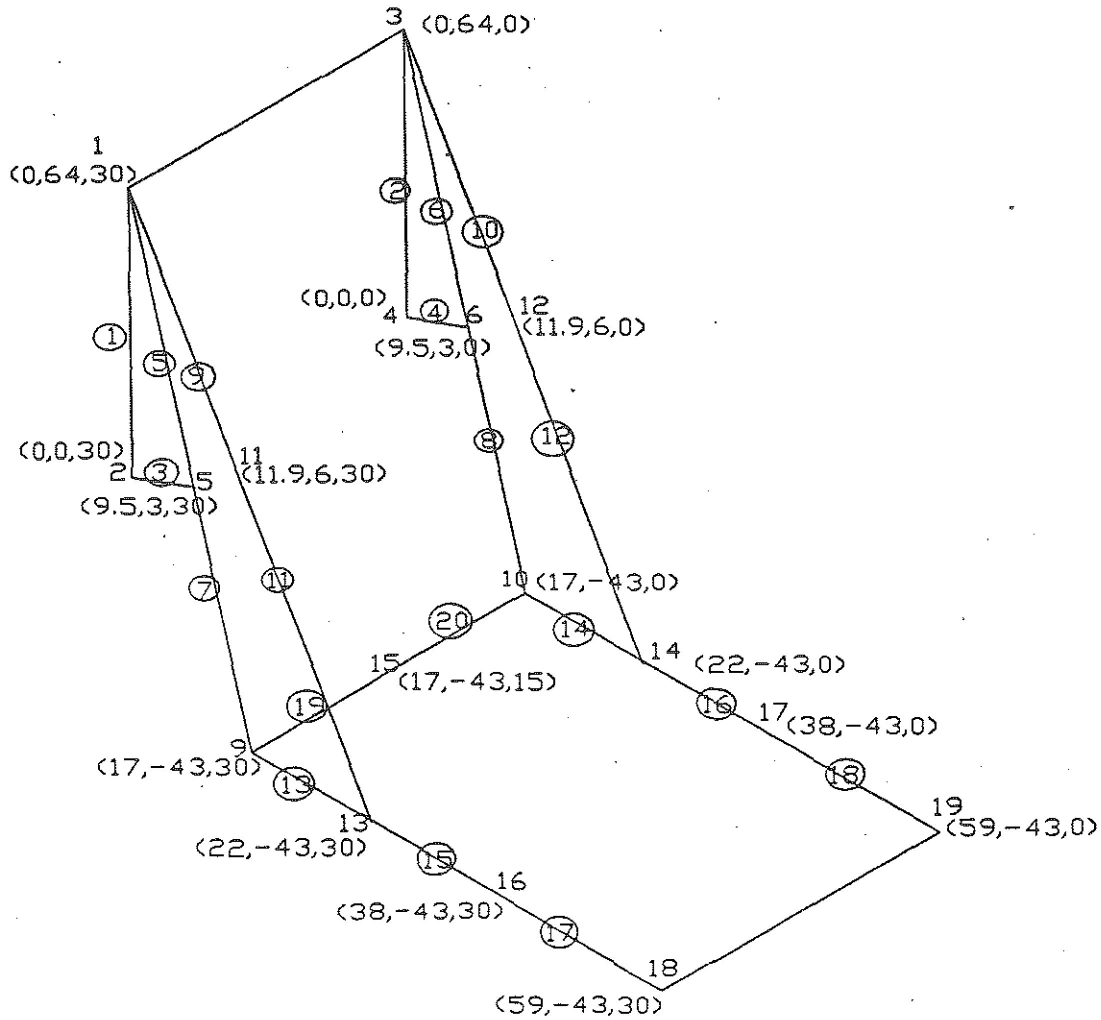


Figure-26. Discretisized Model of Fully Deployed Lift.

boundaries and the connectivity between each element. The structural model is described by seven element groups for two element types. The element types are 3-dimensional beam element and 3-dimensional truss element. A total of 19 nodes and 20 elements describes the FE model.

The 3-dimensional truss elements are described by cross-sectional area only. The three dimensional beam elements are described by the moment of inertias with respect to two orthogonal axis in addition to area. One aspect to note here is the description of hollow square tube sections between nodes 1-5 and 9 in figure 26. that telescope during deployment. In these two elements bending stiffness should be present, however, there cannot be any axial stiffness since, the components are allowed to slide in and out. This requires releasing the axial degree of freedom along the beam axis, but retaining the rotational degree of freedom. Only limited number of finite element programs allow such boundary conditions where the component is unstable. The element groups, node numbers designating the element boundaries, element indexes, cross sectional geometry and geometric properties are given in Table 10. The element groups describe the different cross-sectional geometries.

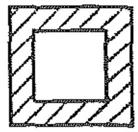
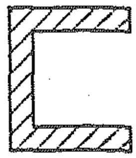
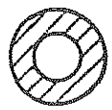
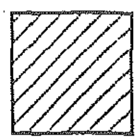
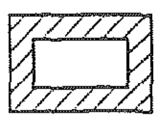
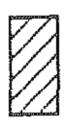
For the purposes of this analysis the interaction of the lift structure with the bus structure is ignored. The lift frame connection to the bus frame connections are assumed fixed.

5.5 **Loading Conditions:**

The lift structural static demand requirements are established as 1000 pounds for service and 2500 pounds for ultimate load. These demand requirements are greater than required by UMTA specifications but, in the opinion of the investigators reflect more realistic loads observed during the operation of lifts.

During deployment and stow away operation the lift structure is subjected to additional static and dynamic loads that are not included in the specifications. Some examples of these load demands

Table-10 Lift Structural Elements Geometry and Properties

ELEMENT	NODES	GEOMETRY	TYPE	PROPERTY
1	1 - 2		BEAM	A=2.5 in**2
2	3 - 4		BEAM	I=2.55 in**4
5	26 - 5		BEAM	Iy=1.3 in**4
6	27 - 6		BEAM	
7	24 - 9		BEAM	A=1.25 in**2
8	25 - 10		BEAM	I=1.12 in**4
				Iy=0.3 IN**4
9	20 - 11		TRUSS	A=1.8 in**2
10	21 - 12			
11	11 - 22		TRUSS	A=1.6 in**2
12	12 - 23			
13	9 - 13		BEAM	A=2.0 in**2
14	10 - 14		BEAM	I=0.34 in**4
15	13 - 16		BEAM	
16	14 - 17		BEAM	
17	16 - 18		BEAM	
18	17 - 19		BEAM	
19	9 - 15		BEAM	A=2.0 in**2
20	15 - 10		BEAM	I=0.635 in**4
				Iy=2.08 in**4
3	2 - 5		TRUSS	A=0.45 in**2
4	4 - 6			

are: inertia force on the lift in the stowed position while the bus is in motion, the upward force from the ground due to lift overextending while deployment (some active lifts include a ground sensor, however, the sensor may be inoperable or ground may be uneven), impact factor at the instance the platform motion is initiated under passenger load, etc. A more critical review of these loading conditions is proposed for further research.

For the purposes of this study, the three loading cases utilized are: service load condition, maximum load to cause yielding of the lift structure and the impact load factor. The service level load is increased to 1000 pounds versus 850 pounds specified to account for the increase due to impact factor. The impact factor is computed using the lift platform velocity of 10 inches/second and a rise time of 0.5 seconds to the maximum velocity which results in an acceleration value of $20 inches/\sec.^2$. This acceleration results in an 110 lbs. of dynamic force. Assuming an impact factor of 1.4 (impact factor is to equate the dynamic force to a static equivalent force and is between 1 and 2) an additional force of 150 lbs. is calculated. Impact factor is a function of rise time and the dynamic properties of the lift structure. The ultimate limit load of 2500 pounds is inclusive of impact load.

The first yield capacity of the lift structure is computed by reanalyzing the structural model under incrementally increasing vertical load until the maximum stress in any component achieves yield strength.

5.6 Finite Element Analysis:

The finite element analysis of the lift structural system is performed using the ANSYS computer program [2]. The ANSYS program also contains a post-processor which allows the visual display of lift structural response. A sample program run is included in Appendix C.

Table-11 Nodal Deformations Under Service Load Condition

NODE	Ux inches	Uy inches	ROTz radians
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5,6	-.000180	.000001	-.002097
9,10	-.299127	-.010911	-.009526
11,12	-.161791	-.033767	-.002798
13,14	-.299136	-.062622	-.011257
15	-.299248	-.023689	-.009526
16,17	-.299136	-.277357	-.014502
18,19	-.299136	-.581915	-.014502
20,21	0	0	-.002787
22,23	-.299136	-.062622	-.002808
24,25	-.005944	.036889	-.002097
26,27	0	0	.001044

Table-12 Nodal Deformations Under Ultimate Load Condition

NODE	Ux inches	Uy inches	ROTz radians
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5,6	-.000451	.000002	-.005243
9,10	-.747818	-.027277	-.023815
11,12	-.404478	-.084419	-.006997
13,14	-.747840	-.156555	-.028143
15	-.748121	-.059224	-.023815
16,17	-.747840	-.693393	-.036256
18,19	-.747840	-1.454788	-.036256
20,21	0	0	-.006969
22,23	-.747840	-.156555	-.007020
24,25	-.014860	.092224	-.005243
26,27	0	0	.002610

Table-13 Element Forces and Moments for Service Load Condition

ELEMENT	NODE	Fx lb	Fy lb	Mz lb-in
1,2	1 3	0	0	0
	2 4	0	0	0
3,4	2 4	225.30	0	0
	5 6	-225.30	0	0
5,6	26 27	33.92	-121.91	0
	5 6	-33.92	121.91	-7526.31
7,8	24 25	0	100.81	7526.31
	9 10	0	-100.81	-2827.80
9,10	20 21	-494.57	0	0
	11 12	494.57	0	0
11,12	11 12	-494.57	0	0
	22 23	494.57	0	0
13,14	9 10	99.60	-234.43	2827.80
	13 14	-99.60	234.43	-4000.00
15,16	13 14	0	250.00	4000.00
	16 17	0	-250.00	0
17,18	16 17	0	0	0
	18 19	0	0	0
19	9	0	250.00	408.28
	15	0	-250.00	2341.70
20	15	0	-250.00	-2341.70
	10	0	250.00	-408.28

Table-14 Element Forces and Moments for Ultimate Load Condition

ELEMENT	NODE	Fx lb	Fy lb	Mz lb-in
1,2	1 3	0	0	0
	2 4	0	0	0
3,4	2 4	563.25	0	0
	5 6	-563.25	0	0
5,6	26 27	84.81	-304.78	0
	5 6	-84.81	304.78	-18815.78
7,8	24 25	0	252.02	18815.78
	9 10	0	-252.02	-7069.52
9,10	20 21	-1236.42	0	0
	11 12	1236.42	0	0
11,12	11 12	-1236.42	0	0
	22 23	1236.42	0	0
13,14	9 10	249.01	-586.09	7069.52
	13 14	-249.01	586.09	-10000.00
15,16	13 14	0	625.00	10000.00
	16 17	0	-625.00	0
17,18	16 17	0	0	0
	18 19	0	0	0
19	9	0	625.00	1020.70
	15	0	-625.00	8354.30
20	15	0	-625.00	-8354.30
	10	0	625.00	-1020.70

The ANSYS program analysis was performed on the College of Engineering super mini computer. A sample input of the lift structural analysis for the ANSYS program is included in Appendix C including comments on input lines. The analysis output contains the deflections of all 19 nodes, the axial stresses in truss members and the bending moment shear force and the axial force in the beam members. Analysis results also includes the principal stresses, computed from the combined bending, shear and axial stress.

The FE analysis of the lift structure is performed independently for the two load conditions of 1,000 and 2,500 pounds. The load 'P' is applied in a group of concentrated load: P/4 pounds at the center of each platform edge beam and P/2 pounds to the center of the platform back beam all acting downward as shown in figure 27 and 28. The analysis results are presented as nodal deformations and component stresses. Table 11 and 12 list the nodal deformations and Tables 13 and 14 lists the element forces. The element forces are axial loads for the truss members and axial, shear forces and bending moments at each end of the beam members. The component stress computations and the shear on the hinges at various locations of the lift structure are described in the following section.

5.7 Discussion of Structural Analysis Results:

The FE analysis results are presented in terms of component forces for the two load conditions corresponding to service and ultimate load cases. The lift operational performance is verified by checking the maximum components deformations under the serviceability load case. More specifically the platform rotation is computed as designated in the UMTA spec. [10]. The lift structural strength performance is checked by computing the component and connection stresses to observe if any yielding has taken place.

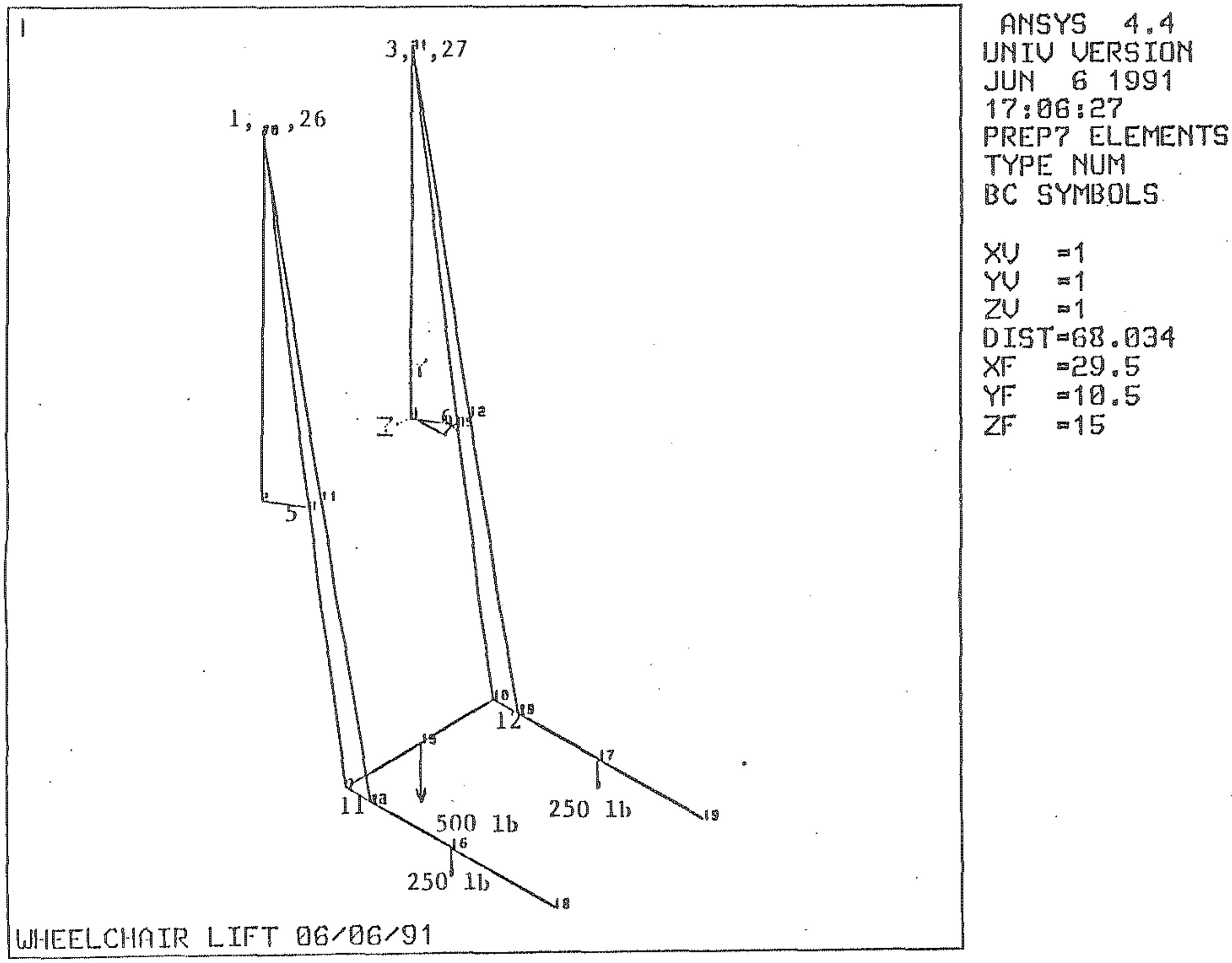


Figure-27. Service Level Loading and Point of Application.

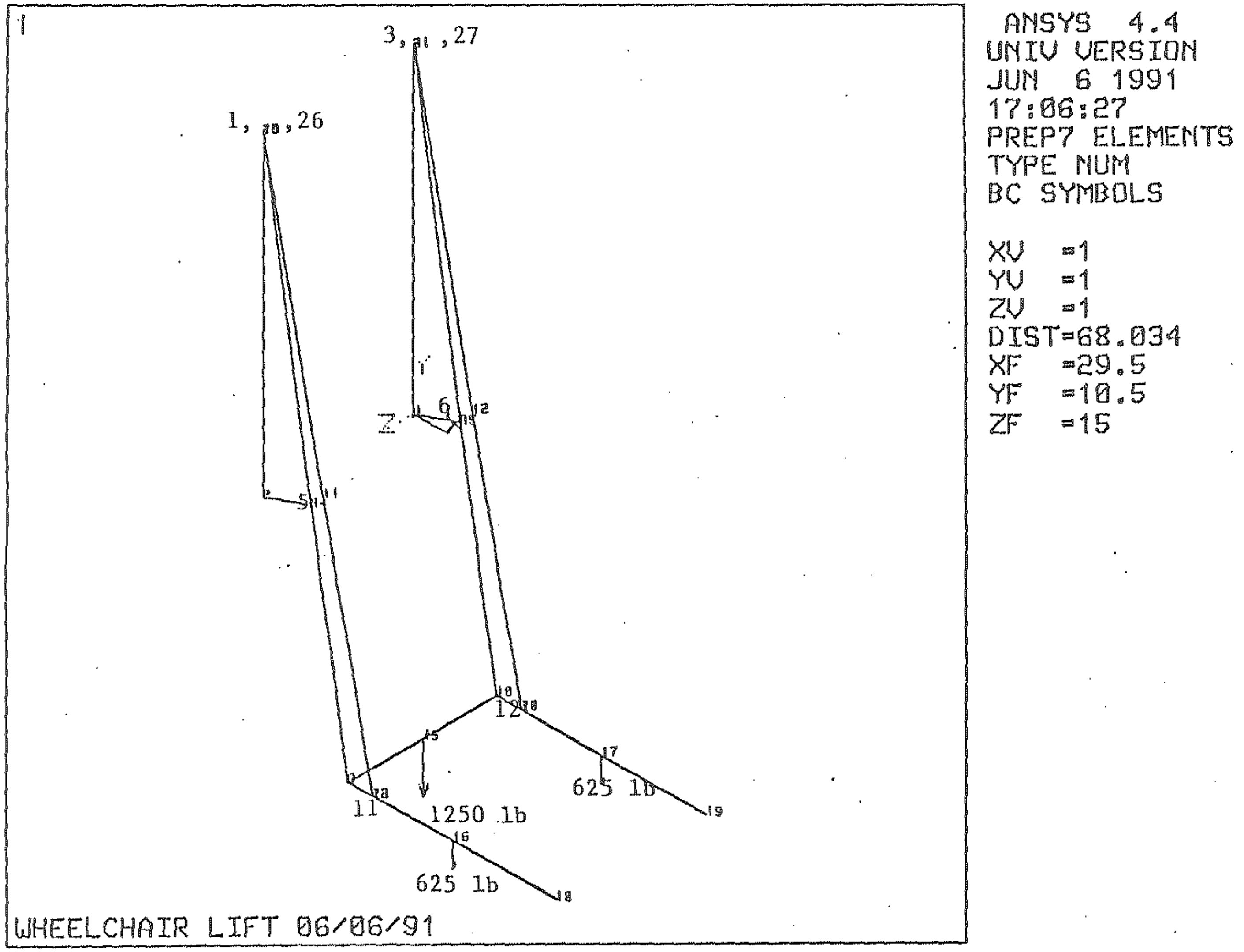


Figure-28. Ultimate Level Loading and Point of Application.

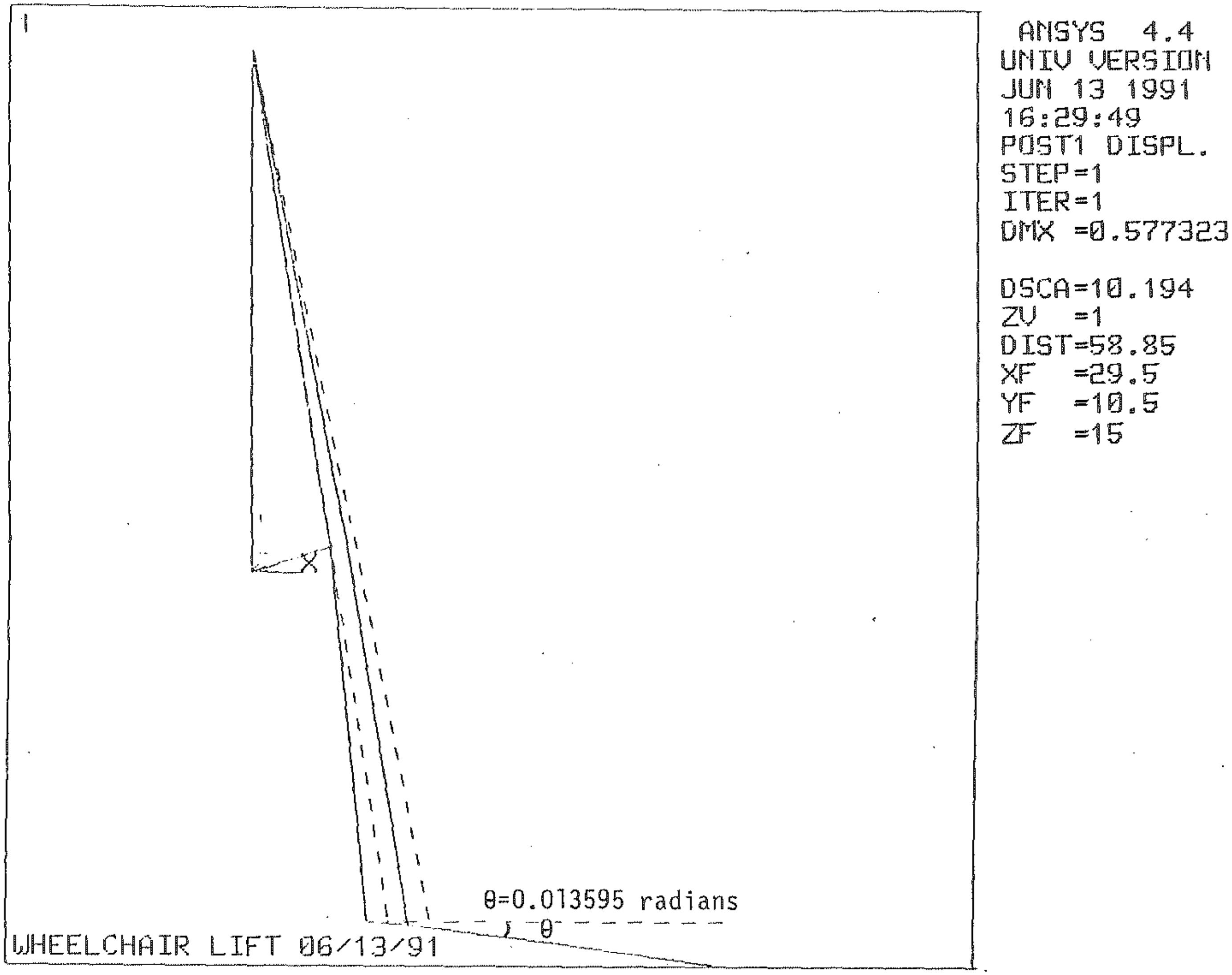


Figure-29. Rotation Computation.

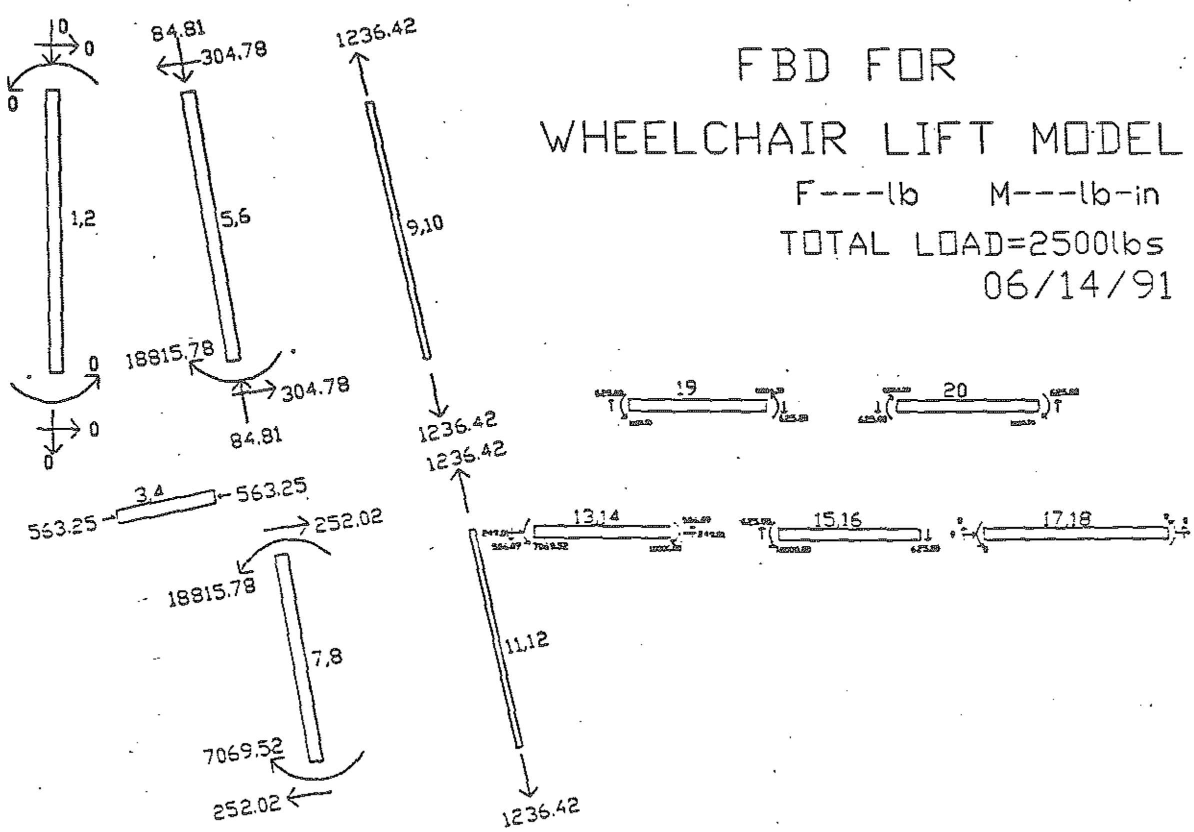
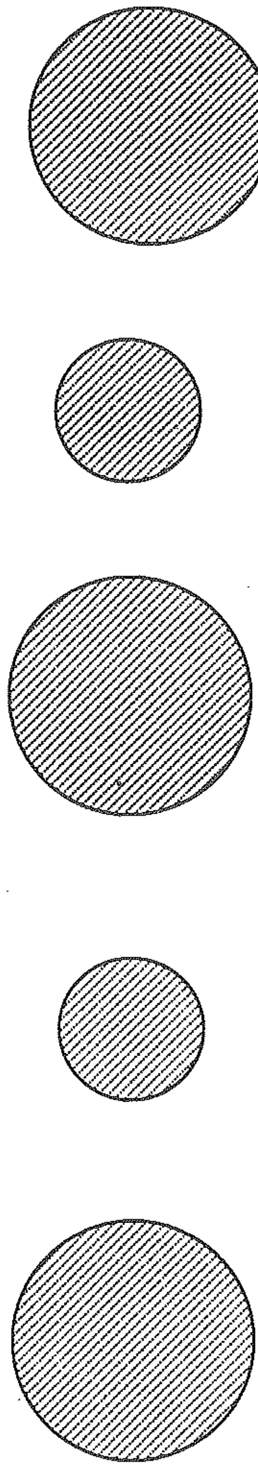


Figure-30. Internal Forces Representation.



Diameter = 0.75 in. At nodes 1 & 3

Shear stress S = 2799 psi.

Diameter = 0.50 in. At nodes 2 & 4

Shear Stress S=2869 psi

Diameter = 0.75 in. At nodes 5 & 6

Shear stress S = 1275 psi.

Diameter = 0.50 in. At nodes 9 &10.

Shear stress S = 1284 psi.

Diameter = 0.75 in. At nodes 13&14

Shear stress S = 2799 psi.

Figure-31. Pins with Different Diameters.

Equilibrium Condition at Nodes 13 & 14

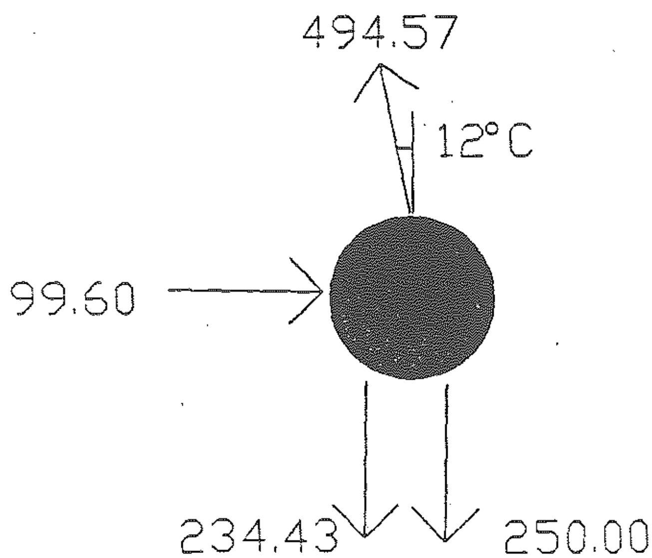


Figure-32. Depiction of Hinge Shear Force.

The platform rotation is computed as the average rotation of the elements 13, 15, and 17 (figure 29). The element rotations are computed from the differential vertical deformation of both ends divided by the element length. Under the service load of 1000 pounds the platform rotation is calculated as 0.7789 degrees lower than the 3^0 as mentioned.

The component stresses are calculated as the maximum uniaxial stress for beam and truss members and as maximum shear stress for pins. The internal force distribution within the lift structure is described in figure 30 under the ultimate load of 2500. pounds. Under the ultimate load, the main frame (element 5) pushes down on the cam bracket (element 3) where, the largest bending moment is computed at the location of the cam bracket and the deployment frame. The majority of components are designed to supply sufficient strength under the ultimate state loads. The components at which the stresses approaches yield is only the cambracket (element 3) and platform side beams (elements 31-37). In addition, there are five sets of pins that provide load transfer between members. The five sets of pins are of different diameters and are located at nodes numbered 1-6 and 9,10,13,14. The shear force in the pins are evaluated from the free body diagram shown in Figure 32. The shearing stress are higher than allowable capacity on pins at nodes 1,3,2,4 and on nodes 13,14.

The finite element analysis of the lift structural system provides the deformations of nodes and stresses of the components. An overall understanding of the structural system and the problem areas are identified. However, the effect of component stresses and nodal deformations on the lift mechanical operation is unclear at this point. The experimental investigation during the second phase will allow the assessment of the lift mechanical operation.

6. SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Summary:

The objectives of this study was to assess the nature and magnitude of problems related to the reliability of the wheelchair lift operation in public transportation buses. The initial investigation included interviews of the transit operators to assess their perception of the problem. Upon the completion of the initial investigation, the wheelchair reliability appeared as a problem of large magnitude for the small non-urban transportation operators. For this reason the lift system utilized as the example repeatedly in this study is the automatic rigid platform lift most commonly used in small and medium buses by the agencies of interest.

This study evaluated the reliability of rigid platform automatic lifts based on statistical analysis using the data provided by the transportation agencies and by deterministic analysis of the lift structural system. It should be emphasized that this study is a fact finding mission and should not be construed as evaluation of lifts of various manufacturers.

The conclusions that are given below are grouped into categories for availability of data and data collection needs, structural performance and structural performance expectations.

6.2 Conclusions

The following conclusions are made based on the structural analysis of the lift:

a) The lift structural system analyzed here satisfies the specifications provided by the transportation agencies.

b) The specifications provided by the transportation agencies was found deficient in load demand definitions, serviceability deformation and operation velocity, acceleration, jerk limitations and certification testing procedures.

c) The finite element model for the purposes of the study was sufficiently accurate. In future studies the model should be refined further especially for high stress regions

d) The critical components of the lift structural system are identified as the cam bracket and several of the connecting pins between components.

The conclusions regarding the statistical analysis of lift failure data is given below:

a) There is strong correlation between miles driven between repairs and time between repairs. However, the correlation coefficients are different for different sample groups. If lift repair is a function of number of cycles, the lift use may be different in each group.

b) It is recommended that all lifts be equipped with electric, electronic or mechanical counters that can be used to determine the number of cycles between repairs. This type of statistical data on lift repairs would be more valuable for reliability analysis.

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APPENDIX - 'A'

OPERATOR QUESTIONNAIR SURVEY

Wayne State University
College of Engineering

Department of Civil Engineering
Detroit, Michigan 48202
(313) 577-3789

January 24, 1990

Dear

The Department of Civil Engineering and the Urban Transportation Institute, Wayne State University are conducting a study to examine the design, manufacturing and operational aspects of wheel chair lifts used for assisting the physically handicapped passengers board and unboard transit buses. The project is jointly sponsored by the UPTRAN Division of the Michigan Department of Transportation and the U.S. Department of Transportation and is an attempt to assess the nature of the problems associated with the operation of the lift mechanism and to develop solution strategies. As a part of the fact-finding mission, we would like to ask you the following questions in an effort to compile a data base that is essential for this study.

PLEASE NOTE YOUR INDIVIDUAL RESPONSES WILL BE KEPT CONFIDENTIAL

(1) What is the current bus fleet size that your agency operates under each of the following category?

Large ____________, Medium ______________, Small _____________

(2) Can you indicate what percentage of vehicles in each category is currently equipped with wheel chair lifts?

Large __________%, Medium ____________%, Small _____________%

(3) Do you have any driver training program to acquaint the driver with the operation of wheel chair lifts. Does the manufacturer provide you with an operation manual?

(4) What brand(s) of lifts does your agency use or propose to use? What brand would you prefer to use, if any?

(5) Do you have specification, in addition to those developed by MDOT for ordering lifts?

(6) Is malfunctioning of wheel chair lifts considered a serious problem in your agency?

(7) Can you briefly tell us about the three most common type of lift operation problems your agency has experienced, (by bus size if possible?)

(8) On a given day, what percentage of lifts are in proper working condition?

Large ____________%, Medium ______________%, Small ________%

(9) Does your agency conduct its own maintenance of wheel chair lift or is the maintenance contracted out to a third party?

(10) Do you have a training program for your mechanics?

(11) Does the manufacturer provide your agency with a maintenance schedule? If so, does the schedule specify the type and frequency of maintenance operation? If yes, go to <u>Question (12)</u>. If no, go to <u>Question (13)</u>.

(12) How closely does your agency follow the manufacturer-suggested maintenance schedule?

(13) (Skip question 13 if you answered 'Yes' to question 11.) Does your agency follow any type of preventative maintenance for the lift mechanism <u>or</u> is repair/maintenance initiated only in case of breakdowns?

(14) Does your agency maintain records of lift maintenance and lift failures? Are these records well-document?

(15) How many of the wheel chair-equipped buses that your agency procured most recently, have their lifts in proper working condition today?

Buses procured 3 years ago, _____ out of ____ in working condition

Buses procured 2 years ago, _____ out of ____ in working condition

Buses procured last year, _____ out of ____ in working condition

(16) In your opinion, is malfunctioning of wheel chair lifts the result of: (Please elaborate on the condition of failure).

(a) - Improper Design
(b) - Inadequate Maintenance
(c) - Improper Manufacturing Process
(d) - Improper Operation
(e) - Combination of the above

We greatly appreciate your cooperation in providing us with the above information. Please note that your individual responses will be kept confidential.

Sincerely,

Snehamay Khasnabis
Professor
Civil Engineering

Haluk Aktan
Associate Professor
Civil Engineering

APPENDIX - 'B'

MANUFACTURER SURVEY

Department of Civil Engineering
Detroit, Michigan 48202
(313) 577-3789

Wayne State University
College of Engineering

February 1, 1990

Dear

The Department of Civil Engineering and the Urban Transportation Institute, Wayne State University are conducting a study to examine the design, manufacturing and operational aspects of wheel chair lifts used for providing handicapped access to transit buses. The project is jointly sponsored by the UPTRAN Division of the Michigan Department of Transportation and the US Department of Transportation. The objective of the study is to assess the nature of problems associated with the operation of the lifts and to develop solution strategies.

As a part of the fact-finding mission, we would like to ask you the following questions in an effort to compile a data base that is essential for this study.

The results of this study will be published in a report by the end of Summer 1990. If you would like to obtain a copy please indicate on your response. We greatly appreciate your cooperation on this matter and will acknowledge your assistance in the report.

If you have any questions please call us at (313) 577-3825 or (313) 577-3915 during working hours.

Sincerely,

Professor's Snehamay Khasnabis and Haluk Aktan

Manufactures Survey on Wheel Chair Lifts

Dear

The Department of Civil Engineering and the Urban Transportation Institute, Wayne State University are conducting a study to examine the design, manufacturing and operational aspects of wheel chair lifts used for providing handicapped access to transit buses. The project is jointly sponsored by the UPTRAN Division of the Michigan Department of Transportation and the US Department of Transportation. The objective of the study is to assess the nature of problems associated with the operation of the lifts and to develop solution strategies. As a part of the fact-finding mission, we would like to ask you the following questions in an effort to compile a data base that is essential for this study.

A) GENERAL

1. What is the exact name of your corporation and/or subsidiary manufacturing wheel chair lifts:

2. Do you supply your product for installation to public transportation buses?

3. What size buse is your product intended for
   a) Small
   b) Medium
   c) Large

If different models of lifts can accomodate more than one bus please specify by model number.

4. What is your sale volume specifically for public transportation buses (expressed as number sold per year)?

5. Do you know of any technical committee of a professional association dealing with the questions of lifts for the handicapped? If yes, are you a member? (Please provide the address and contact person for the association)

B) DESIGN

1. How is your product categorized:
   a) Stand alone lift that requires a seperate entry
   b) Single entry used both by handicapped and nonhandicapped passengers

2. Are functional specifications of your product developed by:
   a) Your engineering staff

b) Public transportation agency ordering the product
c) UMTA
d) Combination of the above (please explain).

3. Have you developed a set of lift design specifications for the following: (Please provide copies of the specs.)
a) Structural
b) Mechanical/Electrical/Hydraulic
c) Environmental

4. What is the design life of the product (expressed in years,number of cycles of operation or combination and may include different numbers for different environmental conditions). If you have more than one product for same use but with different design lives please specify for each product.

C) MAINTENANCE

1. Are the maintenance specifications of your product developed by (please provide copies of the specs.):
a) your engineering staff
b) public agency ordering the product
c) UMTA
d) Combination of the above (please elaborate)

2. Do you provide optional maintenance contracts with agencies? If 'yes' could you provide us with a standart maintenance agreement.

3. Is your product designed to be maintained by:
a) Layperson
b) A layperson with some training
c) A qualified technician

4. Do you provide the following for the agencies:
a) Maintenance training manual
b) Maintenance courses either at the agency or at customer location
c) Local maintenance/repair offices

D) OPERATION

1. Are the operational specifications of your product developed by:
a) your company

b) public agency ordering the product
c) UMTA
d) Combination of the above (please specify)

2. Do you provide operation training aids such as, training courses, training manuals (self teaching), videotapes, etc. Please, explain and provide copies.

3. Is your product designed to be operated by:
a) A layperson
b) A layperson with training
c) The bus driver

APPENDIX - 'C'

ANSYS INPUT DECK

ANSYS INPUT DECK

ANSYS	CALL ANSYS
/INTER	SPECIFY INTERACTIVE SESSION
/TITLE, WHEEL CHAIR LIFT	SPECIFY TITLE
/SHOW,4107	USING 4107 TERMINAL FOR PLOTS
/PREP7	CALL DATA INPUT ROUTINE
ET,1,4	SPECIFY 3D BEAM ELEMENT TYPE 4
ET,2,8	SPECIFY 3D TRUSS ELEMENT TYPE 8
EX,1,29e6	SPECIFY MODULUS OF ELASTICITY
DENS,1,.000734	DENSITY FOR MATERIAL
R,1,2.5,2.55,1.3,3,2	
R,2,.45	
R,3,2.5,2.55,1.3,3,2	
R,4,1.25,1.12,.38,2.5,1.5	SPECIFY CROSS-SECTIONAL AREA AND
R,5,1.8,1.12,.38,2.5,1.5	MOMENT OF INERTIA FOR ELEMENT
R,6,1.6,1.12,.38,2.5,1.5	GEOMETRY GROUPS 1 THROUGH 8
R,7,2,.34,.34,1.41,1.41	
R,8,2,.635,2.08,1.5,3	
N,1,,64,30	
N,2,,,30	
N,3,,64	
N,4	
N,5,9.5,3,30,-81.12	
N,6,9.5,3,,-81.12	
N,9,17,-43,30	

N,10,17,-43	SPECIFY X,Y,Z COORDINATES FOR
N,11,11.9,6,30	THE NODES 1 THROUGH 24.
N,12,11.9,6	
N,13,22,-43,30	
N,14,22,-43	
N,15,17,-43,15	
N,16,38,-43,30	
N,17,38,-43	
N,18,59,-43,30	
N,19,59,-43	
N,20,,64,30	
N,21,,64	
N,22,22,-43,30	
N,23,22,-43	
N,24,9.5,3,30,-81.12	
N,25,9.5,3,,-81.12	
N,26,,64,30	
N,27,,64	
TYPE,1	INPUTTING ELEMENT TYPE 1
MAT,1	INPUTTING MATERIAL TYPE 1
REAL,1	INPUTTING PROPERTY GROUP 1
E,1,2	ONE ELEMENT BETWEEN NODES 1 & 2
E,3,4	ONE ELEMENT BETWEEN NODES 3 & 4
TYPE,2	INPUTTING ELEMENT TYPE 2
REAL,2	INPUTTING PROPERTY GROUP 2
E,2,5	ONE ELEMENT BETWEEN NODES 2 & 5
E,4,6	ONE ELEMENT BETWEEN NODES 4 & 6

TYPE,1	INPUTTING ELEMENT TYPE 1
REAL,3	INPUTTING PROPERTY GROUP 3
E,26,5	ONE ELEMENT BETWEEN NODES 26&5
E,27,6	ONE ELEMENT BETWEEN NODES 27&6
REAL,4	INPUTTING PROPERTY GROUP 4
E,24,9	ONE ELEMENT BETWEEN NODES 24&9
E,25,10	ONE ELEMENT BETWEEN NODES 25&10
REAL,5	INPUTTING PROPERTY GROUP 5
E,20,11	ONE ELEMENT BETWEEN NODES 20&11
E,21,12	ONE ELEMENT BETWEEN NODES 21&12
REAL,6	INPUTTING PROPERTY GROUP 6
E,11,22	ONE ELEMENT BETWEEN NODES 11&22
E,12,23	ONE ELEMENT BETWEEN NODES 12&23
REAL,7	INPUTTING PROPERTY GROUP 7
E,9,13	ONE ELEMENT BETWEEN NODES 9&13
E,10,14	ONE ELEMENT BETWEEN NODES 10&14
E,13,16	ONE ELEMENT BETWEEN NODES 13&16
E,14,17	ONE ELEMENT BETWEEN NODES 14&17
E,16,18	ONE ELEMENT BETWEEN NODES 16&18
E,17,19	ONE ELEMENT BETWEEN NODES 17&19
REAL,8	INPUTTING PROPERTY GROUP 8
E,9,15	ONE ELEMENT BETWEEN NODES 9&15
E,15,10	ONE ELEMENT BETWEEN NODES 15&10
CP,1,UX,1,20,26	COUPLE DEGREES OF FREEDOM IN UX,UY,
CP,2,UX,3,21,27	UZ FOR NODES 1,20,26 & 3,21,27
CP,3,UY,1,20,26	
CP,4,UY,3,21,27	

CP,5,UZ,1,20,26	
CP,6,UZ,3,21,27	
CP,7,UX,13,22	COUPLE DEGREES OF FREEDOM IN UX,UY,
CP,8,UX,14,23	UZ FOR NODES 13,22 & 14,23
CP,9,UY,13,22	
CP,10,UY,14,23	
CP,11,UZ,13,22	
CP,12,UZ,14,23	
CP,13,UY,5,24	COUPLE DEGREES OF FREESOM IN UY,UZ,
CP,14,UZ,5,24	ROTX,ROTY,ROTZ FOR NODES 5&24
CP,15,ROTX,5,24	
CP,16,ROTY,5,24	
CP,17,ROTZ,5,24	
CP,18,UY,6,25	COUPLE DEGREES OF FREEDOM IN UY,UZ,
CP,19,UZ,6,25	ROTX,ROTY,ROTZ FOR NODES 6&25
CP,20,ROTX,6,25	
CP,21,ROTY,6,25	
CP,22,ROTZ,6,25	
D,1,ALL,0	SPECIFY ALL DISPLACEMENTS AT NODES
D,2,ALL,0	1,2,3 & 4 TO BE ZERO.
D,3,ALL,0	
D,4,ALL,0	
F,16,FY,-250,,17,1	SPECIFY LOADS IN Y DIRECTION OF 250LB.
F,15,FY,-500	AT NODES 16 & 17 AND 500LB. AT NODE 15.
LWRIT	WRITE LOAD STEP 1
FDELE,ALL,FY	
F,16,FY,-625,,17,1	SPECIFY LOADS IN Y DIRECTION OF 625LB.

F,15,FY,-1250	AT NODES 16 & 17 AND 1250LB. AT NODE 15
LWRIT	WRITE LOAD STEP 2
AFWRIT	COPY ALL LOAD CASES TO INPUT FILE
FINISH	EXIT DATA INPUT ROUTINE
/EXEC	EXECUTE IN INTERACTIVE MODE
/INPUT,27	CALL SOLUTION ROUTINE
FINISH	EXIT SOLUTION ROUTINE
/POST1	CALL DATA POST-PROCESSING ROUTINE
STRESS,MAXI,4,19	PRINT MAXIMUM AND MINIMUM STRESSES
STRESS,MINI,4,20	IN EACH ELEMENTS.
STRESS,MAXJ,4,21	
STRESS,STR,8,3	
SET,1	LOAD STEP 1
/OUTPUT,SER.STR	OUTPUT RESULT TO SER.STR FILE
PLDISP,1	PLOT DEFORMED SHAPE
PRSTRS	PRINT STRESSES RESULT
SET,2	LOAD STEP 2
/OUTPUT,ULT.STR	OUTPUT RESULT TO ULT.STR FILE
PLDISP,1	
PRSTRS	
FINISH	EXIT POST-PROCESSING ROUTINE.
/EOF	EXIT FROM ANSYS.