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RESEARCH ANALYSIS CORPORATION

Operation, Maintenance, and Lifetimes of M60 Tanks, M113 Armored Personnel Carriers, and M88 Tank Recovery Vehicles (U)

Volume II

RAC

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HEADQUARTERS
DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

17 May, 1965

CRD/J

SUBJECT: RAC-T-460, Volume II, "Operation, Maintenance, and Lifetimes of M60 Tanks, M113 Armored Personnel Carriers, and M88 Tank Recovery Vehicles (U)"

C.6 CYS

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1. Reference letter, CRD/J, dated 5 April, 1965 subject: RAC-T-460, Volume I, "Operation, Maintenance, and Lifetimes of M60 Tanks, M113 Armored Personnel Carriers, and M88 Tank Recovery Vehicles (U)."

2. Letter, reference 1, above, transmitted Volume I of RAC-T-460 and indicated that Volume II would be forwarded when published. Transmitted herewith is(are) 1 copy(copies) of RAC-T-460, Volume II.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

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Operations Research Division

Incl
as

SUPPORT SYSTEMS DIVISION
TECHNICAL MEMORANDUM RAC-T-460
Published May 1965

Operation, Maintenance, and Lifetimes of M60 Tanks, M113 Armored Personnel Carriers, and M88 Tank Recovery Vehicles (U)

Volume II

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APPENDIXES

Operation, Maintenance, and Lifetimes of M60 Tanks, M113 Armored Personnel Carriers, and M88 Tank Recovery Vehicles (U)

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ABBREVIATIONS

APC	armored personnel carrier
CINCUSAREUR	Commander in Chief, United States Army, Europe
CWF	Current Work File
DA	Department of the Army
DCSLOG	Deputy Chief of Staff for Logistics
EAM	electronic accounting machine
FSN	Federal Stock Number
MWO	modification work order
QM	Quartermaster
ROAD	reorganization objective, Army divisions
SSI	stock, storage, and issue
TAERS	The Army Equipment Records System
TAPER	temporary appointment pending establishment of register
TOE	table(s) of organization and equipment
USAREUR	United States Army, Europe

Appendix A

IN-USE EFFECTIVE LIFE

Tables

INTRODUCTION

An important action in the management of equipment fleets is the replacement of an item of equipment. Replacement is a simultaneous declaration of the final consumption of the investment in the old item and of the commitment of a significant added investment for the new item. Important factors that should be considered in reaching a decision to replace are obsolescence of equipment relative to its defined mission, obsolescence of the defined mission in current and future tactics, and the total cost of fulfilling the mission effectively. In this study, projections of the first and third of these factors are combined in determining an "effective life"—an age at which more effective performance per dollar in the long run can be achieved by replacing an item than by continuing to operate the old item in its then current condition. The second factor is treated by assuming that the range of mission requirements will remain relatively unchanged.

This appendix consists of four parts. The first is a detailed description of the effective life model. The second is a discussion of the formula modifications necessary to reflect changes in vehicle utilization. The third is a description of the development of the necessary parameters from the study data. The fourth is a presentation of the detailed results of the calculations of lifetimes made.

MODEL

The in-use effective life of the equipment under study is defined as the age at which the minimum of a specific mathematical function combining measures of vehicle effectiveness and cost occurs when the function's parameters are those determined from field experience data.

Two monetary costs are considered: the initial investment cost and the maintenance costs. Costs are amortized in equal amounts for each time period in the life of the item beginning with the time period in which the cost was incurred. Costs are allocated against a defined effectiveness by attributing the effectiveness over a finite time period to the total of the costs amortized in the same time period.

Relative effectiveness is defined as a product of three factors: a measure of technological competitiveness (the inverse of obsolescence), a measure of equipment reliability, and a measure of equipment availability.

The model assumed that relative competitiveness $C(t)$ decays in time continuously and exponentially as $C(t) = (1+i)^{-t}$, where i is the obsolescence rate expressed as the ratio of competitiveness lost during a unit of time to the competitiveness at the beginning of the unit of time. With this convention, relative competitiveness can always be assigned unit value at an arbitrary zero time.

Reliability in unit time is defined by $R(t) = 1 - h(t)$, where $h(t)$ is the frequency of equipment failures per end item per time unit. The formula is an approximation to $e^{-h(t)}$. The latter form must be used when $h(t)$ is not small.

Availability is defined by $A(t) = 1 - \lambda h(t)$, where λ is the mean time out of service per equipment failure regardless of reason. The formula is an approximation to $1/[1+\lambda h(t)]$ for small values of the product $\lambda h(t)$.

The condensed symbolic statement of relative effectiveness $q(t)$ is: $q(t) = C(t) \cdot R(t) \cdot A(t)$.

A perfect, ageless item would have to have no decay in competitiveness $(i = 0)$ and no failures during use $[h(t) = 0]$. For such an item its relative effectiveness remains at unit value indefinitely. Real items have changing effectiveness values of less than unity.

The model combines costs and effectiveness by forming an unlimited number of quotients $c(t)/q(t)$ that may be regarded as expressing an amortized cost per unit of perfect effectiveness at time t. The model determines the mean $E(T)$ of the quotients over a life T. The effective in-use life is defined as the age T, for which $E(T)$ is minimum.

The mathematical statement of $E(T)$ is a specific construct using the ideas and notation introduced above. Let I be the cost of replacing the item, c_i the cost of maintenance in time period i, and q_i the relative effectiveness in time period i. For discrete intervals the average cost per unit of perfect effectiveness at the end of the first time period is $(I + c_1)/q_1$; after the second period it is

$$\frac{1}{2}\left(\frac{I/2+c_1/2}{q_1} + \frac{I/2+c_1/2+c_2}{q_2}\right);$$

at the end of the nth period it is

$$1/n\left[\frac{I/n+c_1/n}{q_1} + \frac{I/n+c_1/n+c_2/(n-1)}{q_2} + \ldots + \frac{I/n+c_1/n+c_2/(n-1)+\ldots+c_{n-1}/2+c_n}{q_n}\right].$$

A rearrangement of the last expression gives as the average cost per unit of perfect effectiveness per time period at the end of n periods

$$E(n) = 1/n\left\{I/n \sum_{i=1}^{n} 1/q_i + \sum_{i=1}^{n}\left[c_i/(n-i+1) \sum_{j=i}^{n} 1/q_j\right]\right\}.$$

The model for discrete intervals has been made continuous by deriving the limiting form as the time periods are made arbitrarily small and the age t represented by the n original intervals is held constant, to yield

$$E(t) = 1/t\left[I/t \int_0^t ds/q(s) + \int_0^t c(s)\,(t-s) \int_s^t dr/q(r)\,ds\right]$$

as the average cost over age t per unit of perfect effectiveness per unit of time at age t. The effectiveness function $q(s)$ is $q(s) = (1+i)^{-s}[1-h(s)][1-\lambda h(s)]$; $h(s)$ was approximated from field data by $h(s) = a + bs$, and $q(s)$ was then quite well approximated by $q(s) = fe^{-gs}$. The maintenance cost function $c(s)$ was approximated from field data by $c(s) = A + Bs$. Introducing these functions into the expression $E(t)$ gives

$$E(t) = 1/t \left[I/t \int_0^t ds/fe^{-gs} + \int_0^t (A+Bs)/(t-s) \int_s^t dr/fe^{-gr}\, ds \right].$$

Integrating $E(t)$ yields as the working expression used in this study for the average cost per unit of perfect effectiveness per unit of time over the age t

$$E(t) = I(e^{gt}-1)/fgt^2 - A/f\, e^{gt}/gt \sum_{m=1}^{\infty} (-gt)^m/m(m!) - Bt/f\, e^{gt}/gt \sum_{m=1}^{\infty} (-gt)^m/m(m+1)!$$

$E(t)$ is evaluated for values of t until T such that $E(T)$ = minimum $E(t)$ is found. T is the defined effective in-use life of the item.

MODIFICATION OF FORMULA FOR CHANGES IN VEHICLE USE

In order to compare current vehicle models with those studied previously it was necessary to convert field observations to a common rate of vehicle use. Such conversions are also necessary to determine in-use lives at any other moderate levels of vehicle use.

Two of the input functions are considered to be explicitly sensitive to utilization. Of course any derived functions that depend on those two input functions are also sensitive to vehicle utilization. The lives of parts were considered to be the same with respect to miles for moderate changes in utilization. Costs were considered to consist of a portion constant with respect to time and another portion unchanged with respect to miles for moderate changes in vehicle utilization.

Let u_o be the observed rate of use. Let u be some other rate of use. Then the assumptions about sensitivity to rate of use when applied to the linear estimates derived from direct observation yield for another rate of use u:

$$h(t) = u/u_o\, [a + (u/u_o)\, bt]$$

$$c(t) = A_1 + u/u_o\, [A_2 + (u/u_o)\, Bt]$$

where A_1 is the portion of cost always constant with respect to time and A_2 is the portion of cost that remains the same with respect to miles.

To emphasize dependence on utilization the input functions are sometimes represented by $h(t, u)$ and $c(t, u)$. Any rate function that depends only on mileage transforms along a time axis according to the functional relation

$$f(t, u) = u/u_o\, [f(u/u_o)t,\, u_o]$$

DEVELOPMENT OF MODEL PARAMETERS

The input data required by the model are of two categories: cost and effectiveness.

Costs

The end-item replacement costs I were taken to be an average of recent procurement prices for vehicles for which lives were computed in this study.[1] Table A1 contains the values of the I parameters used in the life formula.

TABLE A1

Replacement Costs I of Vehicles and Mobility Systems Considered in the Study

Vehicle type	Replacement cost, dollars
M60 tank	146,000
M60 tank mobility system	67,500
M113 APC	26,700
M113 APC mobility system	11,500
M88 recovery vehicle	132,000

TABLE A2

Direct Track Costs per Vehicle

Vehicle type	Dollars per		
	Complete set	Mile	Month[a]
M60 tank	4520	2.05	266.50
M113 APC	3415	.95	137.75
M88 recovery vehicle	6553	4.05	380.60

[a]At observed usage rates.

The mobility systems of the M60 tank and the M113 armored personnel carrier (APC) were considered to consist of the power train and the suspension system. The mobility system cost for each vehicle was developed by totaling the replacement cost of individual parts and components.

Maintenance costs comprised the following: parts, parts management overhead, and labor. Parts costs were treated in four ways, one for each of three categories into which parts were classified during the study, and a special one for track.

Track cost was considered as having been incurred evenly over the track life. Track life varies only slightly. In reality track costs are incurred cyclically over short, well-defined periods of vehicle life, resulting in temporary maintenance costs that are as much as five times the amount incurred during periods when track is not replaced. With track costs made uniform the more gentle maintenance-cost trends of other parts can be well represented by a linear approximation. Table A2 shows track costs for the vehicles discussed in this study.

The three general categories into which parts were classified are major assemblies, selected parts, and other parts. Selected parts were parts considered to be important both for their costs and for their impairment of vehicle effectiveness on failure. The selected parts, including major assemblies, are listed for M60 tanks and M113 APCs in Tables 12 and 13, Chap. 5, Vol I. Data for major assemblies and selected parts were collected for all vehicles in the RAC sample. Data for all other parts were collected for only two battalions of tanks and three battalions of APCs. From replacement rates based on the total sample, selected parts costs were computed for each interval of observed vehicle life. By a least-squares regression a straight line was fitted to these points. The ratio of other parts costs to total parts costs excluding major assemblies and track was calculated for the units from which all parts data had been collected and analyzed. This ratio was assumed to be constant over vehicle life, and the regression coefficients of the selected parts costs were enlarged to include other parts as well.

Major assembly (engine and transmission) costs were computed as were selected parts costs, and a least-squares linear regression was applied to them.

The approximation of total parts cost is a straight line that is the sum of the individually calculated major assembly and non-major assembly lines.

Parts management overhead, often called "stock, storage, and issue" (SSI) costs, was taken to be 52 percent of the cost of parts excluding major assemblies and track. This factor is taken from "The Cost of Supply Operations"[2] and is the same as that used in the previous RAC combat vehicle study.[3]

Labor costs at crew, company, and battalion level were taken essentially from Ref 3, with adjustment in the pay rate to reflect recent military pay raises. The conversion of the units in the RAC sample to ROAD TOEs occurred late in the study, so that through most of the study the TOE maintenance support remained as it had been during the previous study. The crew sizes of the vehicles did not change. The distribution of all available maintenance man-hours at company and battalion levels among the several studied and nonstudied vehicle types was assumed to be the same as that determined in the previous study. Field-maintenance labor costs were derived from data of the current study. Labor costs for all field maintenance performed were determined from a two-battalion subsample of tanks, a three-battalion subsample of APCs, and the total sample of M88 recovery vehicles. For each vehicle an average field-maintenance labor cost per vehicle month was computed for the observed vehicle life. Table A3 shows crew, company, battalion, and field (i.e., first-, second-, and third-echelon) labor costs for the three vehicles.

TABLE A3

Labor Costs per Vehicle per Month

Echelon	M60	M113	M88
Crew (first echelon)	$342.74	$ 77.00	$ 0 [a]
Company (second echelon)	164.18	140.58	262.90
Battalion (second echelon)	66.80	65.56	98.78
Field (third echelon)	2.80	4.56	2.29
Total	576.52	287.70	363.977

[a]No regularly assigned crew. Crew filled from regular maintenance personnel.

Figures A1, A3, and A5 show all assigned maintenance costs for the three vehicles including the labor costs as shown in Table A3. For purposes of comparison Figs. A2, A4, and A6 show all assigned costs when crew labor costs

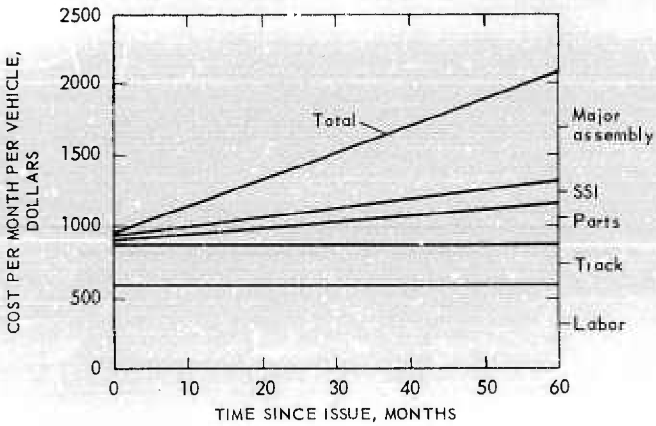


Fig. A1—M60 Tank Maintenance Costs per Vehicle per Month, including First-, Second-, and Third-Echelon Labor Costs Based on Available Maintenance Man-Hours and Averaged over Vehicle Life

Average utilization, 130 miles per vehicle per month.

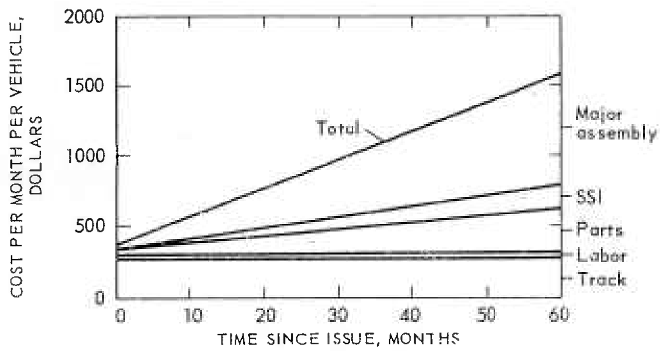


Fig. A2—M60 Tank Maintenance Costs per Vehicle per Month, including Only Maintenance Labor Recorded as Expended at Second and Third Echelons, and excluding Inspections and MWOs

Average utilization, 130 miles per vehicle per month.

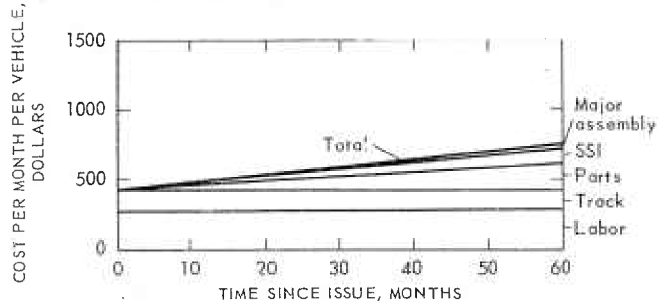


Fig. A3—M113 APC Maintenance Costs per Vehicle per Month, including First-, Second-, and Third-Echelon Labor Costs Based on Available Maintenance Man-Hours and Averaged over Vehicle Life

Average utilization, 147 miles per vehicle per month.

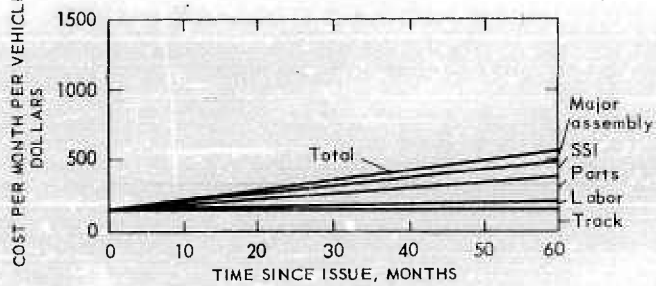


Fig. A4—M113 APC Maintenance Costs per Vehicle per Month, including Only Maintenonce Lobor Recorded as Expended at Second ond Third Echelons, and excluding Inspections and MWOs

Average utilization, 145 miles per vehicle per month.

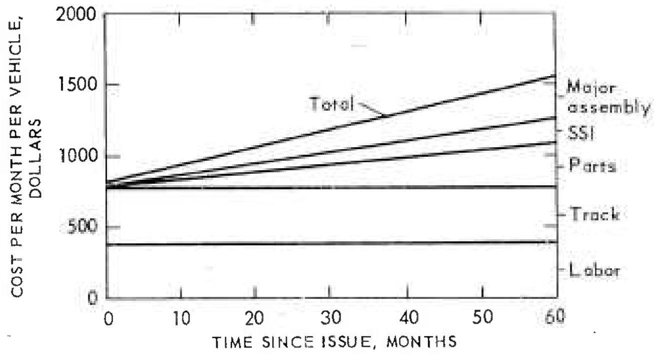


Fig. A5—M88 Recovery Vehicle Maintenance Costs per Vehicle per Month, including First-, Second-, and Third-Echelon Labor Costs Based on Available Maintenance Man-Hours and Averaged over Vehicle Life

Average utilization, 94 miles per vehicle per month.

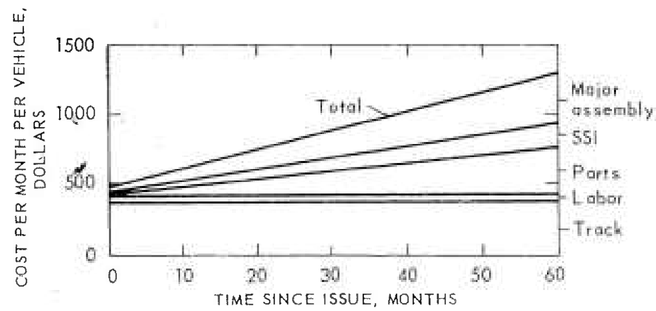


Fig. A6—M88 Recovery Vehicle Maintenance Costs per Vehicle per Month, including Only Maintenance Labor Recorded as Expended at Second and Third Echelons, and excluding Inspections and MWOs

Average utilization, 94 miles per vehicle per month.

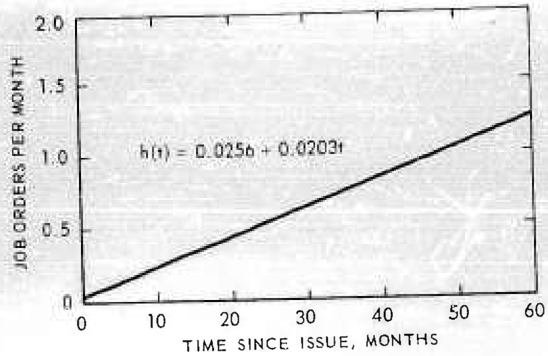


Fig. A7—M60 Tank Maintenonce Job Orders per Vehicle per Month

Average utilization, 130 miles per tank per month.

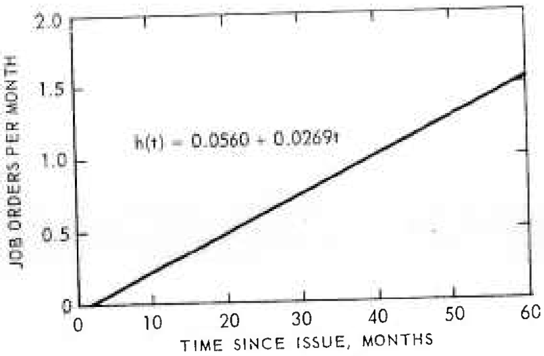


Fig. A8—M113 APC Mointenonce Job Orders per Vehicle per Month

Average utilization, 147 miles per APC per month.

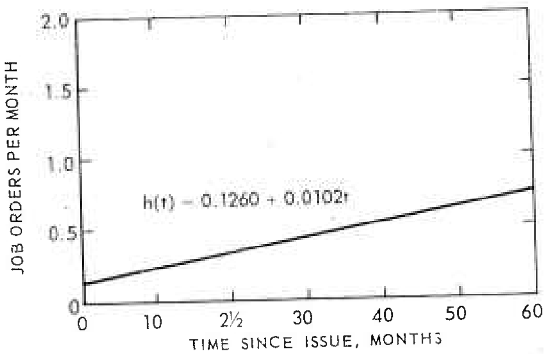


Fig. A9—M88 Recovery Vehicle Mointenance Job Orders per Vehicle per Month

Average utilization, 94 miles per recovery vehicle per month.

are excluded and when the only second- and third-echelon maintenance labor costs included are those based on man-hours actually recorded on job orders. The resulting labor costs are considerably lower than those shown in Table A3, with a corresponding decrease in total maintenance costs.

Effectiveness

Three pieces of information are required to express effectiveness as it is defined in the preceding part of this appendix: i = obsolescence rate, $h(t)$ = vehicle failure frequency, and λ = mean time out of service per failure. All except one of the obsolescence rates used in this study were taken from RAC-T-409.[3] The exception is that used for the M60 tank, which was taken from a more recentanalysis[4] of the kind done in RAC-T-409,[3] and which included a longer history of tanks. (The obsolescence rate used for the M48 tank was 0.050 [5 percent per year]. The effect of using 0.050 instead of 0.056 for the M60 tank would be to extend the effective in-use lives from 6200 miles and 48 months to 6500 miles and 50 months.) The obsolescence rate is assumed constant over the time frame considered by the study. Obsolescence rates used for vehicles in the study are shown in Table A4.

TABLE A4

Annual Obsolescence for Vehicles and Mobility Systems

Vehicle type	Yearly obsolescence, i
M60 tank	0.056
M60 tank mobility system	0.020
M113 APC	0.020
M113 APC mobility system	0.020
M88 recovery vehicle	0.020

TABLE A5

Mean Time Out of Service per Maintenance Job Order Involving Replacement of Prime Mobility Parts

Vehicle type	Job duration, Months
M60 tank	0.19
M113 APC	0.22
M88 recovery vehicle	0.35

The vehicle failure frequency was taken to be the sum of failure frequencies of prime mobility parts. (Lists of the parts for the M60 tank and the M113 APC are contained in Table 6 of Chap. 4, Vol 1.) A least-squares linear regression for the failure frequencies and vehicle ages was made and used as $h(t)$ in life calculations. Figures A7 to A9 show $h(t)$ for the vehicles discussed in this study.

The mean time out of service per maintenance job was derived from data taken from field-maintenance job orders for third-echelon work and from the deadline report for second-echelon work. The mean time out of service per maintenance job was assumed constant over vehicle life. Table A5 shows the mean times out of service per job for the vehicles studied.

RESULTS

Detailed results of the many lifetime calculations made in the course of this study are contained in Tables A6 to A8. In addition to results based on the "standard" parameters (those presented in the previous section), the influence

TABLE A6

Parameters and Results of the In-Use Life Calculations Made for the M60 Tank, USAREUR

Parameters							Results						
Initial cost I, dollars	Rate of utilization υ, miles month	Obsolescence rate r, % year	Downtime per maintenance job order λ, days	Maintenance cost per 50 miles[a], dollars: Type[b]	At date of issue	Increase per 50 miles	Total maintenance cost, dollars: Parts	Labor	Total of all costs during effective life, dollars	Average cost per mile during effective life, dollars	Average cost per month during effective life, dollars	Effective in-use life: Miles	Months
ENTIRE VEHICLE													
Observed Use Parameters													
146,000	130	5.6	5.2	C	362.18	2.69	38,004	27,385	211,389	34.21	4450	6180	47.5
Rate of Utilization Varied													
146,000	50	5.6	5.2	C	720.56	2.69	26,000	55,947	228,007	47.30	2365	4820	96.4
146,000	77[c]	5.6	5.2	C	514.80	2.69	33,477	42,673	222,150	39.01	3002	5695	74.0
146,000	175	5.6	5.2	C	305.16	2.69	38,928	20,697	205,625	32.74	5728	6280	35.9
146,000	200	5.6	5.2	C	281.58	2.69	38,812	18,103	202,915	32.36	6462	6270	31.4
Initial Cost and Utilization Varied													
50,000	77[c]	5.6	5.2	C	514.80	2.69	19,752	29,853	99,605	24.99	1923	3985	51.8
100,000	77	5.6	5.2	C	514.80	2.69	27,396	37,349	161,745	33.05	2546	4985	64.7
146,000	77	5.6	5.2	C	514.80	2.69	33,477	42,673	222,150	39.01	3002	5695	74.0
200,000	77	5.6	5.2	C	514.80	2.69	37,425	45,896	283,321	46.26	3564	6125	79.5
50,000	130	5.6	5.2	C	362.18	2.69	22,292	19,198	91,490	21.13	2747	4330	33.3
100,000	130	5.6	5.2	C	362.18	2.69	32,360	24,675	157,035	28.22	3669	5565	42.8
146,000	130	5.6	5.2	C	362.18	2.69	38,004	27,385	211,389	34.21	4450	6180	47.5
200,000	130	5.6	5.2	C	362.18	2.69	44,074	30,152	274,226	40.33	5243	6800	52.3
Initial Cost and Utilization Varied, 0 Rate of Obsolescence													
50,000	77[c]	0	5.2	C	514.80	2.69	26,907	26,898	113,805	23.10	1778	4925	64.0
100,000	77	0	5.2	C	514.80	2.69	42,515	49,833	192,348	28.92	2229	6650	86.3
146,000	77	0	5.2	C	514.80	2.69	50,193	55,385	251,578	34.04	2621	7390	96.0
200,000	77	0	5.2	C	514.80	2.69	61,330	62,775	324,105	38.70	2982	8375	108.7
50,000	130	0	5.2	C	362.18	2.69	28,503	22,484	100,987	19.80	2589	5100	39.0
100,000	130	0	5.2	C	362.18	2.69	41,787	28,826	170,613	26.05	3412	6550	50.0
146,000	130	0	5.2	C	362.18	2.69	50,312	32,861	229,173	30.97	4021	7400	57.0
200,000	130	0	5.2	C	362.18	2.69	58,582	36,321	294,903	36.18	4681	8150	63.0
Downtime per Job Order Half of That Observed, Rate of Utilization Varied													
146,000	77[c]	5.6	2.6	C	514.80	2.69	35,335	43,938	225,273	38.18	2926	5900	77.0
146,000	130	5.6	2.6	C	362.18	2.69	42,794	29,979	218,773	32.65	4207	6700	52.0
Labor Costs as Recorded on Job Orders, Rate of Utilization Varied													
146,000	77[c]	5.6	5.2	R	158.56	2.71	40,114	2,451	188,565	29.39	2939	6415	83.3
146,000	130	5.6	5.2	R	153.27	2.71	42,368	1,846	190,214	28.63	3722	6645	51.1
MOBILITY SYSTEM ONLY													
Rate of Utilization Varied, Obsolescence 2%/Year													
67,500	50	2.0	5.2	C	720.56	2.69	24,559	53,741	145,800	31.49	1575	4630	92.6
67,500	77[c]	2.0	5.2	C	514.80	2.69	27,996	37,927	133,423	26.38	2031	5058	65.7
67,500	130	2.0	5.2	C	362.18	2.69	31,009	23,983	122,492	22.64	2945	5410	41.6
67,500	175	2.0	5.2	C	305.16	2.69	29,688	17,296	114,184	21.79	3816	5255	30.0
67,500	200	2.0	5.2	C	284.58	2.69	29,097	14,932	111,529	21.50	4306	5185	25.9

[a] Linear approximation of maintenance cost as it changes through time.
[b] C, constant labor cost. R, labor cost recorded on job orders.
[c] Average rate of utilization of predecessor M48-series tank fleet sample.

TABLE A7

Parameters and Results of the In-Use Life Calculations Made for the M113 Armored Personnel Carrier, USAREUR

Parameters							Results						
Initial cost I, dollars	Rate of utilization u, miles month	Obsolescence rate i, % year	Downtime per maintenance job order λ, days	Maintenance cost per 50 miles[a], dollars			Total maintenance cost, dollars		Total of all costs during effective life, dollars	Average cost per mile during effective life, dollars	Average cost per month during effective life, dollars	Effective in-use life	
				Type[b]	At date of issue	Increase per 50 miles	Parts	Labor				Miles	Months
ENTIRE VEHICLE													
Observed Use Parameters													
26,700	145	2.0	6.6	C	144.77	0.64	8, 65	10,982	46,647	8.43	1228	5535	38.0
Rate of Utilization Varied													
26,700	50	2.0	6.6	C	333.26	0.64	6,889	26,441	60,030	13.06	653	4595	92.0
26,700	87[c]	2.0	6.6	C	210.96	0.64	8,425	17,533	52,658	9.94	865	5300	60.9
26,700	200	2.0	6.6	C	117.49	0.64	8,765	7,825	43,290	7.95	1592	5445	27.2
MOBILITY SYSTEM ONLY													
Rate of Utilization Varied													
11,500	50	2.0	6.6	C	333.26	0.64	4,493	19,305	35,303	10.52	526	3355	67.1
11,500	87[c]	2.0	6.6	C	210.96	0.64	5,387	12,702	29,589	7.71	671	3840	44.1
11,500	145	2.0	6.6	C	144.77	0.64	5,288	8,440	25,228	6.27	907	4025	27.8
11,500	200	2.0	6.6	C	117.49	0.64	5,858	5,387	22,745	5.57	1115	4085	20.4

[a] Linear approximation of maintenance cost as it changes through time.
[b] C, constant labor cost.
[c] Average rate of utilization of predecessor M59 armored personnel carrier sample.

TABLE A8

Parameters and Results of the In-Use Life Calculations Made for the M88 Recovery Vehicle, USAREUR

Parameters							Results						
Initial cost I, dollars	Rate of utilization u, miles month	Obsolescence rate i, % year	Downtime per maintenance job order λ, days	Maintenance cost per 50 miles[a], dollars			Total maintenance cost, dollars		Total of all costs during effective life, dollars	Average cost per mile during effective life, dollars	Average cost per month during effective life, dollars	Effective in-use life	
				Type[b]	At date of issue	Increase per 50 miles	Parts	Labor				Miles	Months
Observed Use Parameters													
132,000	94	2.0	10.5	C	809.64	12.74	35,140	17,125	184,265	42.07	3912	4380	47.1

[a] Linear approximation of maintenance cost as it changes through time.
[b] C, constant labor cost.

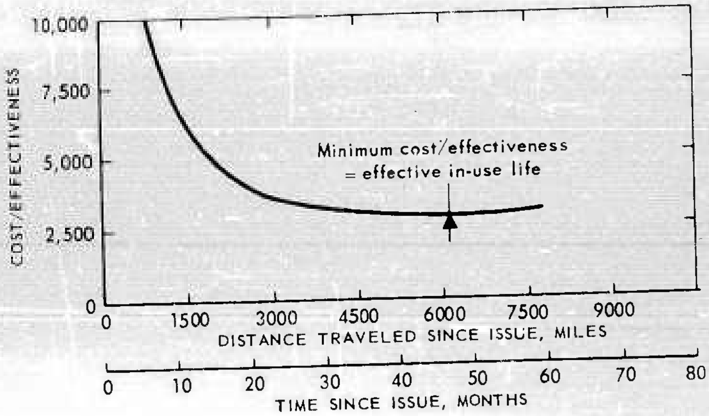


Fig. A10—Effective In-Use Life Curve of M60 Tanks Chorocterized by the Observed Parameters

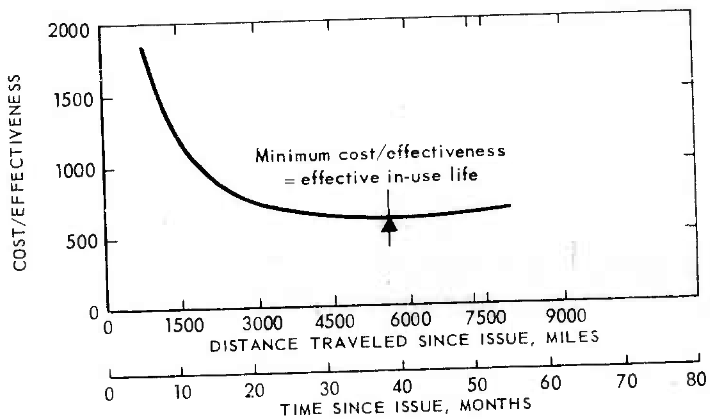


Fig. A11—Effective In-Use Life Curve of M113 APCs Characterized by the Observed Parameters

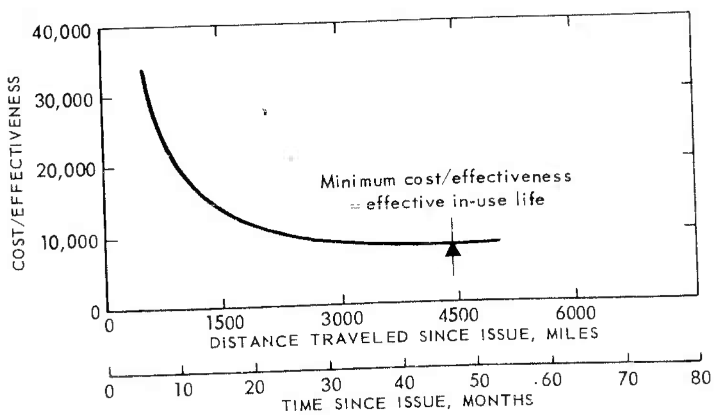


Fig. A12—Effective In-Use Life Curve of M88 Recovery Vehicles Characterized by the Observed Parameters of variations of use rate on tank and APC lives has been examined because of the significant differences between the rate of utilization of the current model vehicles and that of their predecessors.

Furthermore, tank lives were computed for a variety of purchase prices, at both the "standard" obsolescence rate and at a zero obsolescence rate. Also, lives were computed assuming a reduction in downtime of 50 percent.

Labor man-hours as they were recorded on job orders were costed and used as an alternative labor cost input to the calculation. A set of lives to show this effect was also computed.

Finally, lifetimes for mobility systems of the M60 tank and the M113 APC were computed.

All these results are contained in Tables A6 to A8. In most cases the direction of change in the calculated in-use effective life resulting from changing a given parameter is predictable. The magnitude of change is also of interest. For example, the effect of improving (reducing) support system response time by 50 percent is to extend the life 10 percent or less at moderate rates of use.

Graphs of the cost-effectiveness ratio, based on the standard parameters for each vehicle, are plotted in Figs. A10 to A12. These figures show the minimum points that are defined to be the effective in-use lives. The flatness of the curves around their minimums is striking and is discussed in Chap. 7, Vol I.

Appendix B

DATA SOURCES AND SAMPLE SIZES

INTRODUCTION

All operational and maintenance data analyzed by this study were collected directly from Seventh US Army, USAREUR combat and supporting units. The 3d Armd Div and 4th Armd Div were the principal sources of M60 tank data. The 24th Mech Inf Div and 3d Armd Div were the sources of most M113 APC information. The records of M88 recovery vehicles were extracted in all visited units that possessed them. More than 1400 combat vehicles comprise the total sample.

Five battalions were designated "depth" or maximum-detail units. In these five battalions all data relating to all combat-vehicle maintenance activity were extracted. In the remaining units, data extraction was confined to information related to a limited list of parts and assemblies. The depth units were among the first in USAREUR to receive the then new models of combat vehicles. They were also among the first to inaugurate the "temporary appointment pending establishment of register" (TAPER) record-keeping system, the immediate predecessor of The Army Equipment Records System (TAERS).

SOURCE RECORDS: TAERS

TAERS followed TAPER and was begun by some units in Europe as early as January 1962. By October 1962 TAERS had been introduced to all units. Most of the data analyzed in this study describe events that occurred during periods of TAERS coverage.

A TAERS logbook is assigned to each combat vehicle. The book consists of the following operational, maintenance, and equipment historical records:

The Equipment Daily-Monthly Log (DA Form 2408-1)

This form provides a daily record of miles and/or hours operated and fuel and oil consumed. It also provides a month-by-month summary of vehicle operation.

Equipment Maintenance Record (Organizational) (DA Form 2408-3-1)

This form provides a record of maintenance service and parts replacement performed by organizational (second-echelon) personnel.

Equipment Maintenance Record (Support Echelon—Field and Depot) (DA Form 2408-6)

This form provides a record of field-maintenance (third-echelon) repair and parts replacement.

Equipment Transfer Record (DA Form 2408-7)

The date of issue of a vehicle to the possessing unit is recorded on this page.

Forms not contained in equipment logbooks were also examined.

Transaction Register for Supply Actions

In the five depth battalions the parts-requisition registers were photocopied at four 6-month intervals to provide a 2-year record of all parts requisitioned by the battalions.

Maintenance Request (DA Form 2407)

This form is used by organizational units to request maintenance services, repairs, and modification work orders (MWO) to be performed by their supporting field-maintenance units. Field-maintenance units complete the form by recording their responses to the requests.

Although all field-maintenance work on each vehicle should have been recorded on the DA Form 2408-6 page of its logbook, several instances of omission were discovered. In order to guarantee completeness of vehicle histories the supporting field-maintenance units were visited and their records carefully examined.

Earlier Sources

Prior to the introduction of TAPER and TAERS the principal sources of information at organizational units were the Organizational Equipment File (DA Form 478) and the Current Work File (CWF). DA Form 478 provided a reasonably accurate record of major-assembly history that could be checked against data at field-maintenance units. The Current Work File was often too sketchy and too subject to local interpretation to offer more than a fraction of the type of data desired from it.

DATA COLLECTION

RAC data collection teams vistied USAREUR four times from February 1962 through September 1963. Earlier experience had shown 6 months to be an efficient and convenient interval between collection trips.

The data for each vehicle examined were recorded on an individual RAC data sheet. Important identifying information was used to head each page: using unit, vehicle type and model, USA registration number, bumper number, and date of issue. The serial numbers of original and replacement engines and transmissions were recorded when available. The columnar arrangements of the main portion of the RAC data sheets closely corresponded to those of the logbook pages.

Experience showed that logbook data extraction-in-depth battalions generally required 4 to 5 man-days and that ½ to 1 man-day was required for reproduction of the parts-requisition register. Other battalions generally required 2 to 4 man-days for the extraction of logbook data. Data extraction at a supporting field-maintenance unit averaged 1 to $1\frac{1}{2}$ man-days with variation depending directly on the number of sampled battalions supported by the visited unit. At field maintenance only the DA Forms 2407 for units belonging to the RAC sample were pulled and recorded. Man-hours were also consumed in entrance and exit interviews, travel, team conferences, and personal and mechanical maintenance. Several special tests and exercises were attended by one or two team members. All involved headquarters-coordinated visits and thereby greatly boosted team efficiency.

DATA REDUCTION TO PUNCHED CARDS

To be of value the collected data had to be reduced to a workable data bank. Because the data were intended to be used as the input to various analyses by this and other projects, it was advisable to convert the original data to accessible sortable form. Punched cards were chosen as being best suited to the manifold requirements. They could easily be used both for the many required one-time mechanical sorts and counts and also for the more highly repetitive sorting, counting, and calculating routines performed electronically. The project's efforts can be described in order as:

(a) The construction of an empirical history file of maintenance and parts events.

(b) A series of different analytic operations all performed on the history file (data bank).

(c) Interpretations of all processes and analyses.

The transfer of data to punched cards may be considered to mark the completion of the first of these three steps.

The original data were all converted to one of four card arrangements. All these cards are being retained at RAC for future analyses. Arrangements can be made for responsible agencies and individuals to gain access to the bank of reduced historical data. The four types of punched cards are described in the following paragraphs.

History Card

There is one history card for each vehicle in the sample. It contains identification by vehicle type and model, using unit, USA registration number, date and mileage at issue, and date and mileage at last observation. Any pertinent remarks describing such things as evacuation, transfer, or wreckage are also included. All calculations of the days in use and mileages that elapsed prior to some event must be determined by reference to the history cards.

Parts Card

The parts card contains several kinds of information extracted from equipment logbooks. The title "parts card" has been used because most of the included information describes parts replacements; however, other types of events are also recorded. For the five battalions studied in detail, all parts repairs, adjustments, and replacements are described. In the other units, only activity directly involving certain selected parts (Table 13, Vol I) are recorded. For all units, scheduled maintenance jobs (Q services) are each represented by a card. Both organizational- and field-maintenance-activity data are described in parts cards.

Field-Maintenance Cards

Previously unrecorded data (i.e., missed at using units) discovered at supporting field-maintenance units are identified by a separate type of card with format and contained information very similar to that of parts cards. The only real distinction between parts and field-maintenance cards is the source of their included information. In an early stage of data reduction, information that appeared in both organizational and field-maintenance units also appeared in two separate RAC cards. Duplication was later eliminated by retaining only the more complete card. When both a parts and a field-maintenance card were complete, the latter was dropped.

Requisition Register

Information included on the photocopies of requisition registers was punched directly into cards. The cards contain using unit, vehicle bumper number, vehicle USA registration number, date of order, date of delivery, quantity, federal stock number, abbreviated parts nomenclature, and disposition (filled or canceled).

Summary

Data reduction was the most time-consuming phase of the project's efforts. The processes employed were all straightforward. The data came from dozens of units and had to be edited for consistency and nonduplication at all steps. Editing and correcting were primarily manual operations. It was not practical to develop a computer routine general enough to handle all the editing chores. The analytical routines employed in later stages of the study required highly refined input. If the only objective had been to print histories of vehicles, a much less refined data bank would have been sufficient and much editing could have been omitted. However, multiple edits and checks were required to put the TAERS-type data into a form analyzable by RAC.

SAMPLE DENSITY BY UNIT

One of the basic operations performed on the data bank of vehicle histories was the construction of a descriptive summary of the density of the sample and the average vehicle age and mileage for the various units studied. Battalion-by-battalion listings of the number of vehicles studied, months of coverage, average monthly mileage, and average accumulated mileage are given for M60 tanks, M113 APCs, and M88 recovery vehicles in Table B1.

Distributions of months covered and accumulated mileages are shown for the total samples of each vehicle in Figs. B1 to B6. In Figs. B7 to B10, distributions for each armored division of M60 tanks of the sample are shown.

TABLE B1

Sample of Three Vehicle Fleets, Seventh Army, USAREUR

Unit	Number of vehicles	Average months in service	Average miles per month	Average total mileage
M60 Tank				
3d Armd Div	250	23	142	3264
3/33d Armor	54	23	124	2859
3/12th Armd Cav Regt	31	19	179	3406
2/32d Armor	66	22	137	3024
1/33d Armor [a]	77	24	161	3856
2/33d Armor	22	23	117	2702
4th Armd Div	323	20	115	2305
2/15th Armd Cav Regt	20	20	124	2473
24th Engr	7	6	145	870
2/35th Armor	55	21	112	2347
1/37th Armor	55	20	120	2391
3/37th Armor	48	20	124	2485
2/37th Armor [a]	56	21	118	2472
4/35th Armor	72	21	103	2173
Special training veh	10	15	96	1434
24th Inf Div	67	22	131	2871
1/70th Armor	33	22	127	2792
2/70th Armor	34	22	134	2947
Total average, USAREUR	640	21	130	2739
M113 APC				
24th Inf Div	357	18	164	2945
3d Bde	7	14	173	2418
1/19 Inf	68	18	132	2382
1/21 Inf	82	18	157	2830
2/21 Inf	72	17	174	2957
1/34 Inf	31	18	158	2840
3/19 Inf [a]	78	21	174	3656
2/34 Inf	19	20	139	2772
3d Armd Div	185	18	155	2796
3/33 Armor	14	14	108	1506
1/33 Armor	17	14	129	1806
3/36 Inf [a]	61	20	155	3097
1/48 Inf [a]	27	19	189	3583
2/48 Inf	66	16	170	2726
4th Armd Div 51st Inf	63	14	111	1557
2d Armd Cav Regt	64	17	116	1964
1/2 Armd Cav Regt	20	17	128	2184
2/2 Armd Cav Regt	23	18	110	1973
3/2 Armd Cav Regt	21	16	109	1744
14th Armd Cav Regt	38	22	100	2206
1/14 Armd Cav Regt	19	23	98	2265
2/14 Armd Cav Regt	19	20	107	2147
Total average, USAREUR	707	18	147	2654

TABLE B1 (continued)

Unit	Number of vehicles	Average months in service	Average miles per month	Average total mileage
M88 Recovery Vehicle				
3d Armd Div	26	19	93	1760
3/33 Armor	5	18	92	1654
3/12 Armd Cav Regt	6	17	105	1783
2/32 Armor	5	20	80	1607
1/33 Armor	6	18	109	1963
3/36 Inf	1	29	59	1722
2/36 Inf	1	15	109	1630
2/33 Armor	2	20	91	1815
4th Armd Div	27	17	98	1662
2/35 Armor	6	16	103	1643
1/37 Armor	6	19	92	1754
3/37 Armor	1	19	111	2109
2/51 Inf	3	18	68	1217
4/35 Armor	6	17	105	1793
2/37 Armor	5	18	90	1615
24th Inf Div	10	20	76	1516
3/19 Inf	5	19	45	857
1/70 Armor	2	22	101	2226
2/70 Armor	3	20	107	2142
2d Armd Cav Regt	10	19	79	1508
1/2d Armd Cav Regt	2	22	88	1933
2/2d Armd Cav Regt	4	16	82	1310
3/2d Armd Cav Regt	4	20	75	1493
14th Armd Cav Regt	10	21	114	2404
1/14 Armd Cav Regt	6	24	119	2847
2/14 Armd Cav Regt	4	19	92	1740
Total average, USAREUR	83	19	94	1746

[a]Subject of intensive data collection and analysis.

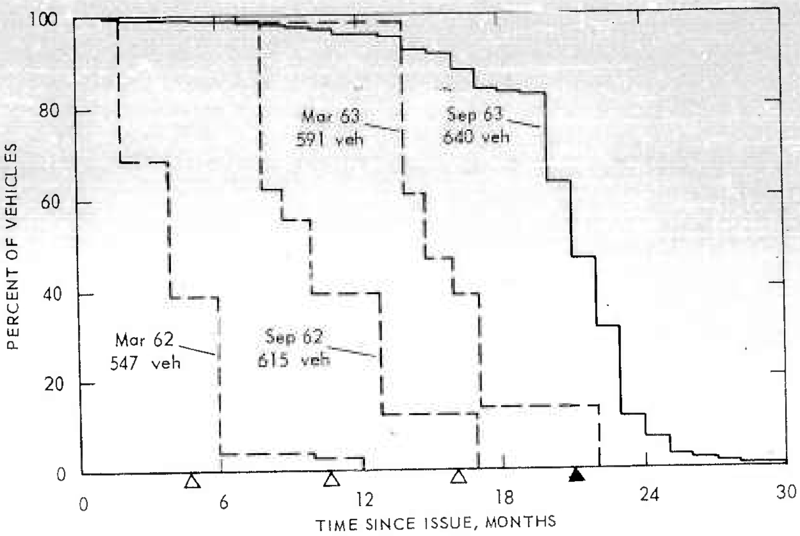


Fig. B1—Age Distribution of M60 Tanks Observed in USAREUR during Four Data-Gathering Trips

△ Average age of sample at end of each of first three data-gathering periods
▲ Average age of total vehicle sample
– – – Age distribution of sample observed during each of first three data-gathering trips
——— Age distribution of total vehicle sample

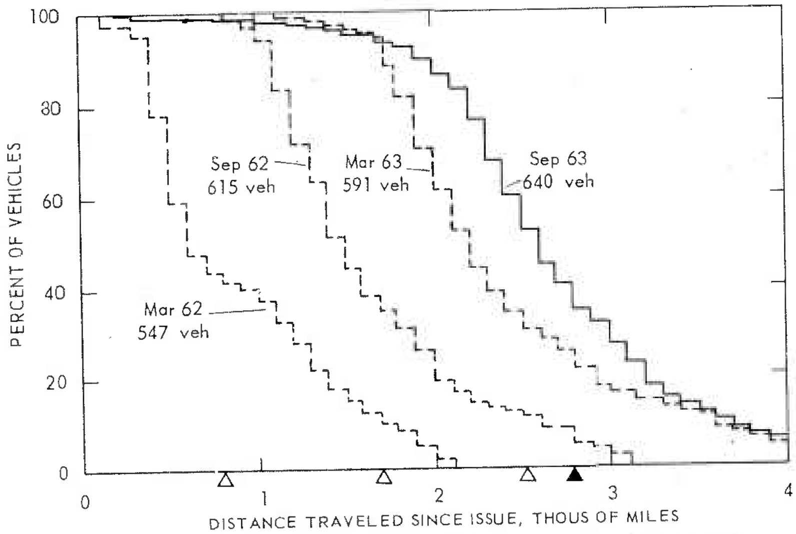


Fig. B2—Mileage Distribution of M60 Tanks Observed in USAREUR during Four Data-Gathering Trips

△ Average mileage of sample at end of each of first three data-gathering periods
▲ Average mileage of total vehicle sample
– – – Mileage distribution of sample observed during each of first three data-gathering trips
——— Mileage distribution of total vehicle sample

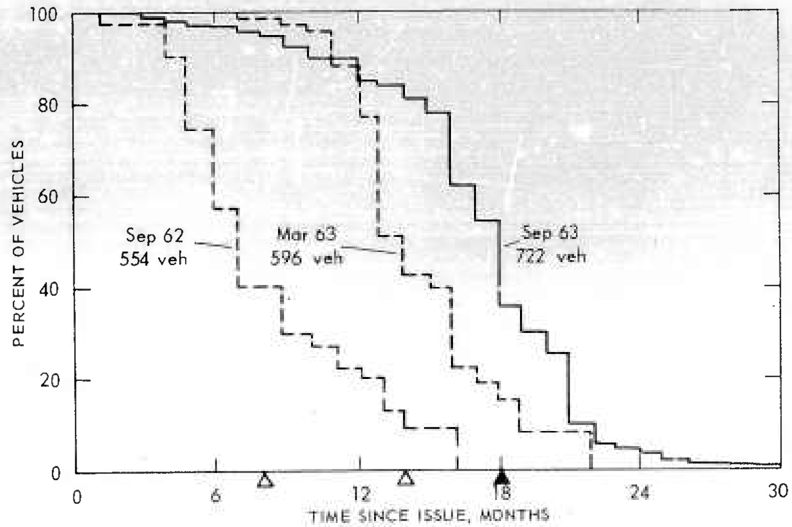


Fig. B3—Age Distribution of M113 APCs Observed in USAREUR during Three Data-Gathering Trips

△ Average age of sample at end of each of first two data-gathering periods
▲ Average age of total vehicle sample
– – – Age distribution of sample observed during each of first two data-gathering trips
—— Age distribution of total vehicle sample

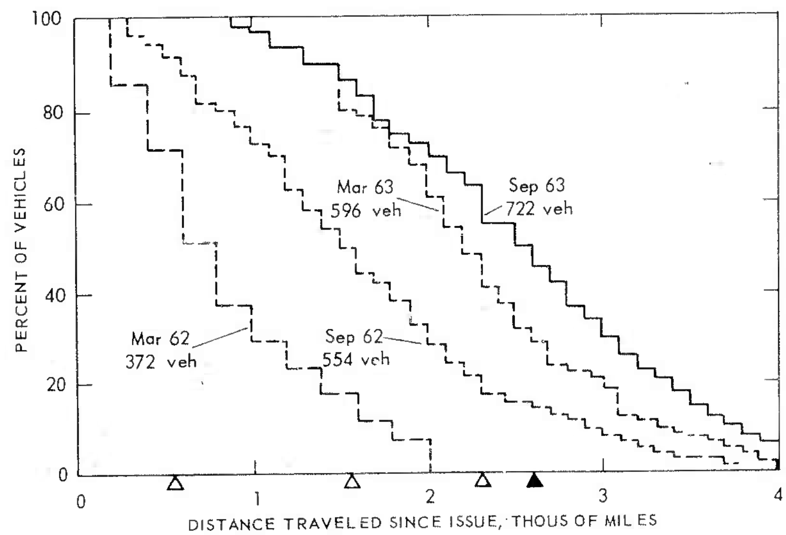


Fig. B4—Mileage Distribution of M113 APCs Observed in USAREUR during Four Data-Gathering Trips

△ Average age of sample at end of each of first three data-gathering periods
▲ Average age of total vehicle sample
– – – Age distribution of sample observed during each of first three data-gathering trips
—— Age distribution of total vehicle sample

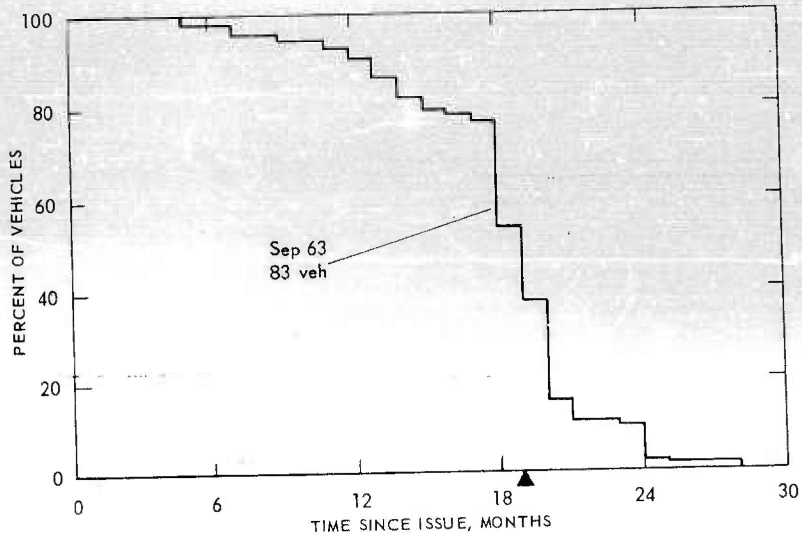


Fig. B5—Age Distribution of M88 Recovery Vehicles Observed in USAREUR

▲ Average age of total vehicle sample

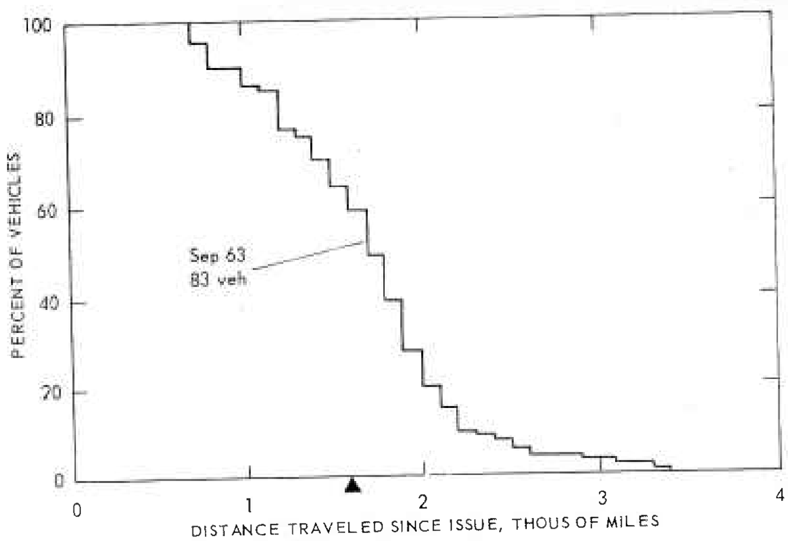


Fig. B6—Mileage Distribution of M88 Recovery Vehicles Observed in USAREUR

▲ Average mileage of total vehicle sample

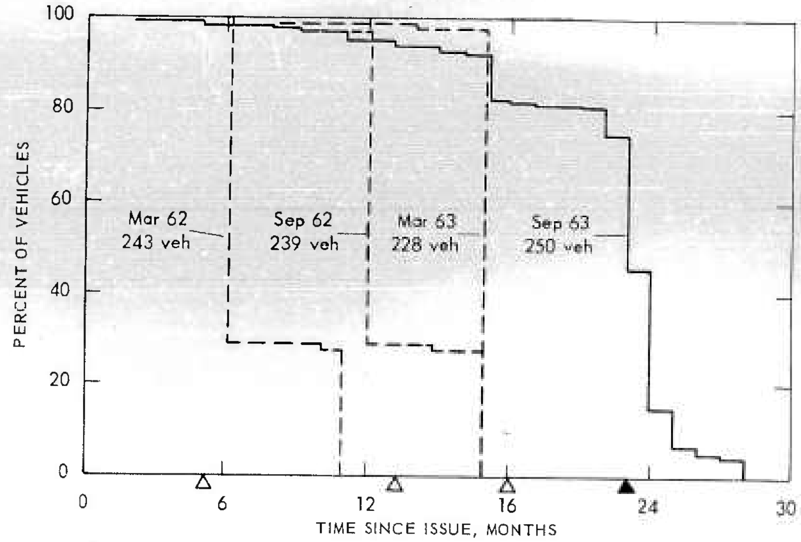


Fig. B7—Age Distribution of M60 Tanks Observed in 3d Armd Div, USAREUR during Four Data-Gathering Trips

△ Average age of sample at end of each of first three data-gathering periods
▲ Average age of total vehicle sample
– – – Age distribution of sample observed during each of first three data-gathering trips
——— Age distribution of total vehicle sample

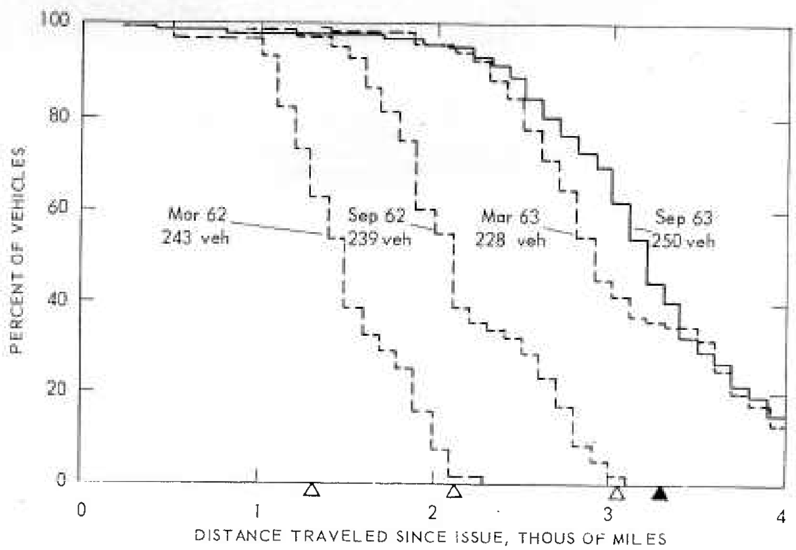


Fig. B8—Mileage Distribution of M60 Tanks Observed in 3d Armd Div, USAREUR, during Four Data-Gathering Trips

△ Average mileage of sample at end of each of first three data-gathering periods
▲ Average mileage of total vehicle sample
– – – Mileage distribution of sample observed during each of first three data-gathering trips
——— Mileage distribution of total vehicle sample

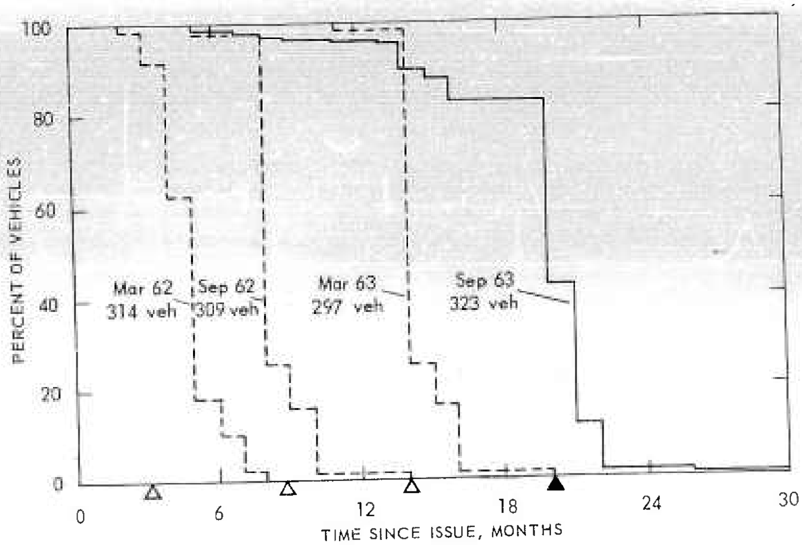


Fig. B9—Age Distribution of M60 Tanks Observed in 4th Armd Div, USAREUR, during Four Data-Gathering Trips

△ Average age of sample at end of each of first three data-gathering periods
▲ Average age of total vehicle sample
– – – Age distribution of sample observed during each of first three data-gathering trips
——— Age distribution of total vehicle sample

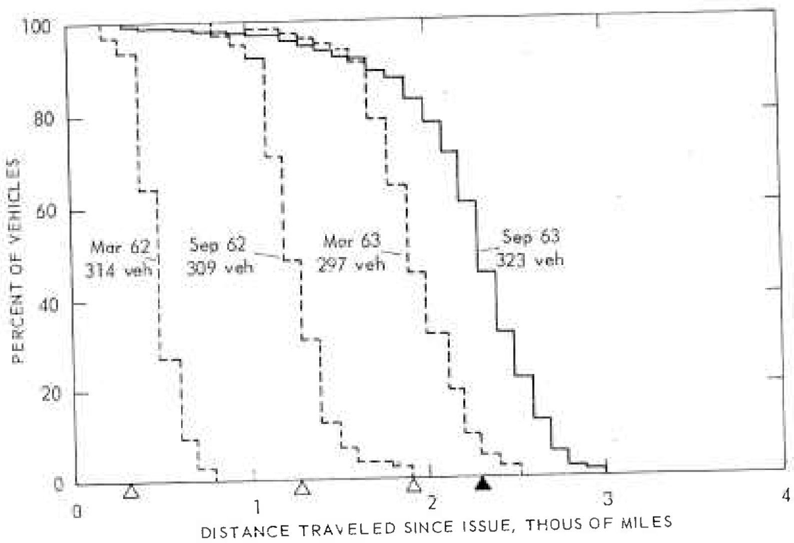


Fig. B10—Mileage Distribution of M60 Tanks Observed in 4th Armd Div, USAREUR, during Four Data-Gathering Trips

△ Average mileage of sample at end of each of first three data-gathering periods
▲ Average mileage of total vehicle sample
– – – Mileage distribution of sample observed during each of first three data-gathering trips
——— Mileage distribution of total vehicle sample

Appendix C

MAINTENANCE EVENTS RATES COMPUTER ROUTINE

INTRODUCTION

The ideas of "maintenance event" and "maintenance-event rate" are basic to an analysis of effects of maintenance on operations. A "maintenance event" is any action taken to correct or prevent an equipment operational deficiency; for example, engine replacement, lubrication, point-gap adjustment, or radiator repair. A "maintenance-event rate" is the frequency at which a maintenance event occurs. Frequency is the ratio of actual occurrences to the total possible occurrences. A maintenance-event rate may be used as a convenient base from which to estimate equipment availability and costs of maintenance by associating labor, parts, supply, storage, and issue costs and elapsed periods of equipment unserviceability with each maintenance event. For events associated with vehicle disablement, the event rates are direct measures of equipment unreliability due to those events and the appropriate combination of all such event rates is a measure of the equipment reliability. And, when the event is a part replacement, the event rate is a parts demand rate.

The reduction of raw data of the form "event x occurred to equipment number y at equipment age z" to an event rate for event x at equipment age z is an important step in maintenance analysis. The computer program described below performs this basic reduction of events data to events rates as a function of equipment age. The equipment sample size may vary with equipment age; the program is designed to process changes in the numbers of event occurrences and of possible event occurrences.

RATES

The calculation is oriented toward events that can occur only once to a particular component of an item of equipment, e.g., "replacement of the second replacement engine." For such events a hazard rate for first (original) components is developed, and a quasi-hazard rate for second- and higher-order components is developed. "Hazard rate" is the event rate expressed as a frequency of event occurrence among only those components that have not yet experienced the event. "Quasi-hazard rate" is used here to describe a rate expressed as a frequency of occurrence among only those items of equipment that have not yet experienced it but is not a true hazard rate in two ways: (a) items of equipment are included in the rate's divisor (rate is a ratio: occurrences/possible occurrences) regardless of whether they have yet experienced necessary prior events (e.g., the divisor of third engine replacements includes all equipments that have not yet experienced third engine replacements, including those that have not yet experienced even their second or their first); (b) it is expressed as a function of equipment age rather than of component age.

Then, from first-event hazard rate, first-event rate is developed, and from second- and higher-order-event quasi-hazard rates, second- and higher-order-event rates are developed. The calculation proceeds to event rates via hazard and quasi-hazard rates to avoid bias in the censoring of the sample by the sample age distribution; the bias introduced when the proportion of event-experiencing equipment among items appearing in age interval but not in $n+1$ differs from the proportion among all equipment appearing in age interval n. In addition, the true hazard rate is itself a fundamental quantity.

Rates for events that are not truly ordered in the sense of 1st, 2d, . . . , nth are also computed using the same routine. However, for these events the output of hazard rates, quasi-hazard rates, and 1st-, . . . , nth-order event rates have no readily useful meaning with respect to event order. The sum of the so-called "1st-, . . . , nth-order event rates," called simply the "event rate" for an event has the intended meaning. Events of this kind may be characterized by any one or combination of the following: the event may occur more than once to the same component; the order of the event may be unknown; and more than one of the same kind of component may be present in the equipment in such a way that the particular one experiencing the event may be unknown.

A brief technical exposition of the rates may be found in App D in the section "Replacement Rates and Mean Lives."

ROUTINE

An outline of the flow and generation of information in the events rates routine is shown graphically in Fig. C1 and verbally below.

The rates-computation routine requires events data consisting of event identification code, equipment serial number, equipment age when the event occurred, and a code indicating whether the event is amenable to an ordered rate interpretation such as that described in the first paragraph of the preceding section, or whether it is amenable to only the nonordered interpretation described in the second. The routine also requires parent-sample identification data, consisting of the serial number, the age at which observation in the sample began, and the age at which observation ended for each item of equipment in the sample. These data are regarded as two files: an events file and an equipment file.

The rates routine assumes the existence and use of an appropriate sort routine. Beginning with the two sorted files, the rates routine proceeds in two phases: in Phase I the desired elements of the two basic data files are placed on one tape; in Phase II the output tape of Phase I is the input from which the rates are computed. In Phase I it is possible to form any subsample of the sample so that rates can be computed on the basis of subsamples, and it is possible to select among the events. The format of Phase I output is a sequence of one or more "jobs," each job being at least two data blocks of which the first is the sample or a subsample, and each of the others is an event the rate of which is to be computed for the equipment sample or subsample of the job. Phase II computes a rate for each event block on the Phase I output tape. Phase II has two parts: part 1 is a frequency count of actual and possible events for age intervals of a length specified as an input to Phase II, beginning at age zero and ending with the interval containing the age of the oldest sample or

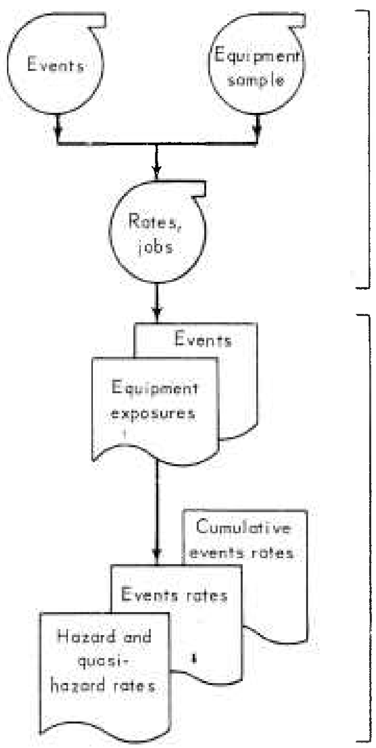


Fig. C1—Flow and Generation of Information in Rates-Computation Routine

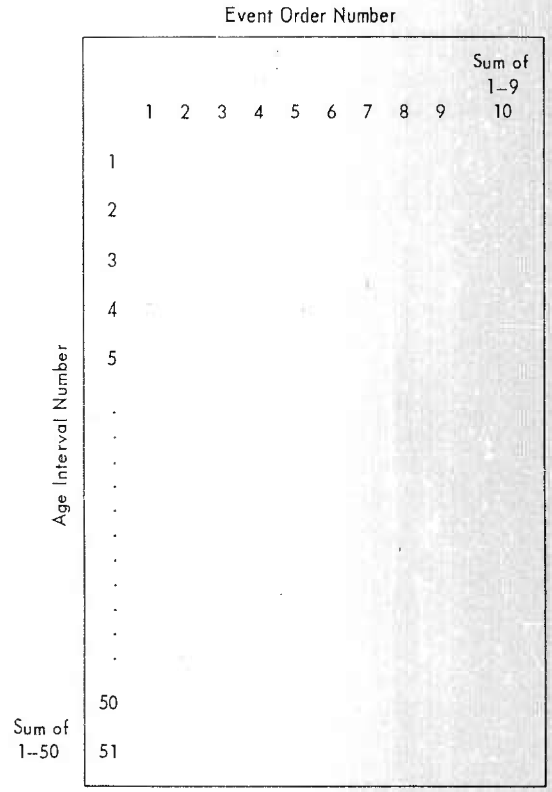


Fig. C2—Rate-Routine Output Page

Pages 2–6 of the six-page set that constitutes an event-rate output. These pages are basically 9 × 50 arrays in which the nine columns from left to right correspond to event orders 1 to 9 and the 50 rows from top to bottom correspond to age intervals numbered 1 to 50 of the size stated on the cover page (page 1) of the set. Sometimes 10th-column and/or 51st-row entries appear; these are row and column sums respectively.

subsample item; part 2 computes hazard and quasi-hazard rates and event rates for each age interval.

The printed output for an event rate is contained on six pages.[5,6] The first page is a cover identifying the event, the sample, and the age interval size. The remaining five pages are of the format shown in Fig. C2, and contain information shown in the accompanying tabulation.

Page	Contents
2	Event count
3	Equipment exposure count
4	Hazard and quasi-hazard rate
5	Event rate
6	Cumulative event rate

A set of output pages for M60 tank engine replacements is shown in Figs. C3 to C8.

```
STUDYRP74.1          29 04 64

MTNC EVENTS RATES VS AGE

VEHICLE          M60 TANK
SAMPLE           TOTAL
AGE SEGMENT       100.MILES
EVENT            ENGINE              JO
```

Fig. C3—Cover Page, Page 1 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

RUNRP74.1   29 04 64   RATES M60   ENGINE RPL   JO   100.MILES

E

E

	2.	0.	0.	0.	0.	0.	0.	0.	0.	
	2.	0.	0.	0.	0.	0.	0.	0.	0.	
	4.	0.	0.	0.	0.	0.	0.	0.	0.	
	4.	1.	U.	0.	0.	0.	0.	0.	0.	
	3.	1.	0.	0.	0.	0.	0.	0.	0.	
	7.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	0.	0.	0.	0.	0.	0.	0.	0.	
	4.	0.	0.	0.	0.	0.	0.	0.	0.	
	3.	0.	0.	0.	0.	0.	0.	0.	0.	
	5.	0.	0.	0.	0.	0.	0.	0.	0.	
	4.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	0.	0.	0.	0.	0.	0.	0.	0.	
	5.	0.	0.	0.	0.	0.	0.	0.	0.	
	6.	1.	0.	0.	0.	0.	0.	0.	0.	
	8.	0.	0.	0.	0.	0.	0.	0.	0.	
	9.	2.	0.	0.	0.	0.	0.	0.	0.	
	15.	2.	0.	0.	0.	0.	0.	0.	0.	
	10.	1.	0.	0.	0.	0.	0.	0.	0.	
	20.	3.	0.	0.	0.	0.	0.	0.	0.	
	8.	4.	1.	0.	0.	0.	0.	0.	0.	
	15.	1.	0.	0.	0.	0.	0.	0.	0.	
	12.	3.	1.	0.	0.	0.	0.	0.	0.	
	9.	1.	0.	0.	0.	0.	0.	0.	0.	
	14.	5.	1.	0.	0.	0.	0.	0.	0.	
	12.	1.	0.	0.	0.	0.	0.	0.	0.	
	11.	0.	1.	0.	0.	0.	0.	0.	0.	
	5.	4.	0.	0.	0.	0.	0.	0.	0.	
	6.	4.	1.	0.	0.	0.	0.	0.	0.	
	6.	1.	0.	1.	0.	0.	0.	0.	0.	
	3.	2.	0.	0.	0.	0.	0.	0.	0.	
	4.	0.	0.	0.	0.	0.	0.	0.	0.	
	2.	2.	0.	0.	0.	0.	0.	0.	0.	
	1.	2.	0.	0.	0.	0.	0.	0.	0.	
	3.	1.	0.	0.	0.	0.	0.	0.	0.	
	4.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	1.	0.	0.	0.	0.	0.	0.	0.	
	2.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	1.	0.	0.	0.	0.	0.	0.	
	1.	1.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	1.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.	0.	0.	
ESUM	235.	44.	6.	1.	0.	0.	0.	0.	0.	286.

Fig. C4—Event-Count Page, Page 2 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

RUNRP74.1 29 04 64 RATES M60 ENGINE RPL J0 100.MILES

V

V

	639.0	639.0	639.0	639.0	639.0	639.0	639.0	639.0	639.0
	635.7	639.0	639.0	639.0	639.0	639.0	639.0	639.0	639.0
	632.2	638.0	638.0	638.0	638.0	638.0	638.0	638.0	638.0
	627.7	636.8	637.0	637.0	637.0	637.0	637.0	637.0	637.0
	623.0	633.5	634.6	634.6	634.6	634.6	634.6	634.6	634.6
	616.2	632.0	634.0	634.0	634.0	634.0	634.0	634.0	634.0
	611.1	630.9	632.9	632.9	632.9	632.9	632.9	632.9	632.9
	606.7	629.0	631.0	631.0	631.0	631.0	631.0	631.0	631.0
	601.1	628.0	630.0	630.0	630.0	630.0	630.0	630.0	630.0
	598.0	628.0	630.0	630.0	630.0	630.0	630.0	630.0	630.0
	591.5	626.8	628.8	628.8	628.8	628.8	628.8	628.8	628.8
	589.3	626.0	628.0	628.0	628.0	628.0	628.0	628.0	628.0
	583.1	623.9	625.9	625.9	625.9	625.9	625.9	625.9	625.9
	573.7	619.4	621.7	621.7	621.7	621.7	621.7	621.7	621.7
	564.4	616.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2
	553.4	610.3	614.6	614.6	614.6	614.6	614.6	614.6	614.6
	538.6	603.0	608.7	608.7	608.7	608.7	608.7	608.7	608.7
	519.1	594.7	602.6	602.6	602.6	602.6	602.6	602.6	602.6
	500.0	586.3	596.3	596.3	596.3	596.3	596.3	596.3	596.3
	478.7	570.0	580.9	581.1	581.1	581.1	581.1	581.1	581.1
	457.6	551.2	562.6	562.6	562.6	562.6	562.6	562.6	562.6
	433.1	530.7	544.1	544.1	544.1	544.1	544.1	544.1	544.1
	405.8	500.4	512.5	513.5	513.5	513.5	513.5	513.5	513.5
	359.2	448.7	459.8	460.9	460.9	460.9	460.9	460.9	460.9
	309.3	395.5	407.0	409.0	409.0	409.0	409.0	409.0	409.0
	255.9	339.1	350.6	353.1	353.1	353.1	353.1	353.1	353.1
	221.0	298.5	309.8	312.4	312.4	312.4	312.4	312.4	312.4
	189.2	258.0	271.4	273.7	273.7	273.7	273.7	273.7	273.7
	163.9	224.3	239.3	240.4	240.4	240.4	240.4	240.4	240.4
	147.4	202.8	215.8	215.8	215.8	215.8	215.8	215.8	215.8
	130.4	179.8	189.1	189.1	189.1	189.1	189.1	189.1	189.1
	114.6	155.3	162.4	162.4	162.4	162.4	162.4	162.4	162.4
	95.6	128.2	134.5	134.5	134.5	134.5	134.5	134.5	134.5
	77.9	104.2	109.3	109.3	109.3	109.3	109.3	109.3	109.3
	70.7	92.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6
	60.2	82.2	86.5	86.5	86.5	86.5	86.5	86.5	86.5
	52.1	70.8	75.2	75.2	75.2	75.2	75.2	75.2	75.2
	43.0	57.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
	36.8	48.6	51.6	51.3	51.3	51.3	51.3	51.3	51.3
	32.3	42.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1
	26.2	34.9	37.0	37.0	37.0	37.0	37.0	37.0	37.0
	20.6	26.7	29.0	29.0	29.0	29.0	29.0	29.0	29.0
	16.1	19.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
	10.6	14.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
	7.0	9.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
	6.1	8.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	2.2	4.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	0.	1.1	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
	0.	0.	0.	0.	0.	0.	0.	0.	0.
VSUM	15429.9	17239.8	17484.9	17497.3	17497.3	17497.3	17497.3	17497.3	17497.3

Fig. C5—Equipment-Exposure-Count Page, Page 3 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

RUNRP74.1 29 04 64 RATES M60 ENGINE RPL J0 100.MILES
RKI

K

0.003	0.	0.	0.	0.	0.	0.	0.	0.
0.003	0.	0.	0.	0.	0.	0.	0.	0.
0.006	0.	0.	0.	0.	0.	0.	0.	0.
0.006	0.002	0.	0.	0.	0.	0.	0.	0.
0.005	0.002	0.	0.	0.	0.	0.	0.	0.
0.011	0.	0.	0.	0.	0.	0.	0.	0.
0.002	0.	0.	0.	0.	0.	0.	0.	0.
-0.007	0.	0.	0.	0.	0.	0.	0.	0.
0.005	0.	0.	0.	0.	0.	0.	0.	0.
0.008	0.	0.	0.	0.	0.	0.	0.	0.
0.007	0.	0.	0.	0.	0.	0.	0.	0.
0.002	0.	0.	0.	0.	0.	0.	0.	0.
0.009	0.	0.	0.	0.	0.	0.	0.	0.
0.010	0.002	0.	0.	0.	0.	0.	0.	0.
0.014	0.	0.	0.	0.	0.	0.	0.	0.
0.016	0.003	0.	0.	0.	0.	0.	0.	0.
0.028	0.003	0.	0.	0.	0.	0.	0.	0.
0.019	0.002	0.	0.	0.	0.	0.	0.	0.
0.040	0.005	0.	0.	0.	0.	0.	0.	0.
0.017	0.007	0.002	0.	0.	0.	0.	0.	0.
0.033	0.002	0.	0.	0.	0.	0.	0.	0.
0.028	0.006	0.002	0.	0.	0.	0.	0.	0.
0.022	0.002	0.	0.	0.	0.	0.	0.	0.
0.039	0.013	0.002	0.	0.	0.	0.	0.	0.
0.039	0.003	0.	0.	0.	0.	0.	0.	0.
0.043	0.	0.003	0.	0.	0.	0.	0.	0.
0.023	0.013	0.	0.	0.	0.	0.	0.	0.
0.032	0.016	0.004	0.	0.	0.	0.	0.	0.
0.037	0.004	0.	0.004	0.	0.	0.	0.	0.
0.020	0.010	0.	0.	0.	0.	0.	0.	0.
0.031	0.	0.	0.	0.	0.	0.	0.	0.
0.017	0.013	0.	0.	0.	0.	0.	0.	0.
0.010	0.016	0.	0.	0.	0.	0.	0.	0.
0.039	0.010	0.	0.	0.	0.	0.	0.	0.
0.057	0.	0.	0.	0.	0.	0.	0.	0.
0.017	0.	0.	0.	0.	0.	0.	0.	0.
0.019	0.014	0.	0.	0.	0.	0.	0.	0.
0.047	0.	0.	0.	0.	0.	0.	0.	0.
0.027	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.023	0.	0.	0.	0.	0.	0.
0.038	0.029	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.062	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	-0.	-0.	-0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.

Fig. C6—Hazard- and/or Quasi-Hazard-Rate Page, Page 4 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

RUNRP74.1 29 04 64 RATES M60 ENGINE RPL J0 100.MILES
RI, R

					RI				R
0.003	0.	0.	0.	0.	0.	0.	0.	0.	0.003
0.003	0.	0.	0.	0.	0.	0.	0.	0.	0.003
0.006	0.	0.	0.	0.	0.	0.	0.	0.	0.006
0.006	0.002	0.	0.	0.	0.	0.	0.	0.	0.008
0.005	0.002	0.	0.	0.	0.	0.	0.	0.	0.006
0.011	0.	0.	0.	0.	0.	0.	0.	0.	0.011
0.002	0.	0.	0.	0.	0.	0.	0.	0.	0.002
0.006	0.	0.	0.	0.	0.	0.	0.	0.	0.006
0.005	0.	0.	0.	0.	0.	0.	0.	0.	0.005
0.008	0.	0.	0.	0.	0.	0.	0.	0.	0.008
0.006	0.	0.	0.	0.	0.	0.	0.	0.	0.006
0.002	0.	0.	0.	0.	0.	0.	0.	0.	0.002
0.008	0.	0.	0.	0.	0.	0.	0.	0.	0.008
0.010	0.002	0.	0.	0.	0.	0.	0.	0.	0.011
0.013	0.	0.	0.	0.	0.	0.	0.	0.	0.013
0.015	0.003	0.	0.	0.	0.	0.	0.	0.	0.018
0.025	0.003	0.	0.	0.	0.	0.	0.	0.	0.028
0.017	0.002	0.	0.	0.	0.	0.	0.	0.	0.018
0.034	0.005	0.	0.	0.	0.	0.	0.	0.	0.039
0.014	0.007	0.002	0.	0.	0.	0.	0.	0.	0.022
0.026	0.002	0.	0.	0.	0.	0.	0.	0.	0.028
0.021	0.006	0.002	0.	0.	0.	0.	0.	0.	0.029
0.017	0.002	0.	0.	0.	0.	0.	0.	0.	0.019
0.029	0.011	0.002	0.	0.	0.	0.	0.	0.	0.042
0.027	0.002	0.	0.	0.	0.	0.	0.	0.	0.030
0.029	0.	0.003	0.	0.	0.	0.	0.	0.	0.032
0.015	0.013	0.	0.	0.	0.	0.	0.	0.	0.028
0.020	0.015	0.004	0.	0.	0.	0.	0.	0.	0.038
0.023	0.004	0.	0.004	0.	0.	0.	0.	0.	0.031
0.012	0.009	0.	0.	0.	0.	0.	0.	0.	0.021
0.018	0.	0.	0.	0.	0.	0.	0.	0.	0.018
0.010	0.012	0.	0.	0.	0.	0.	0.	0.	0.022
0.006	0.014	0.	0.	0.	0.	0.	0.	0.	0.020
0.021	0.009	0.	0.	0.	0.	0.	0.	0.	0.030
0.030	0.	0.	0.	0.	0.	0.	0.	0.	0.030
0.008	0.	0.	0.	0.	0.	0.	0.	0.	0.008
0.009	0.012	0.	0.	0.	0.	0.	0.	0.	0.022
0.022	0.	0.	0.	0.	0.	0.	0.	0.	0.022
0.012	0.	0.	0.	0.	0.	0.	0.	0.	0.012
0.	0.	0.022	0.	0.	0.	0.	0.	0.	0.022
0.017	0.025	0.	0.	0.	0.	0.	0.	0.	0.042
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.027	0.	0.	0.	0.	0.	0.	0.	0.	0.027
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	-0.	-0.	-0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Fig. C7—Event-Rate Page. Page 5 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

RUNRP74.1 29 04 64 RATES M60 ENGINE RPL JO 100.MILES

RIC, RC

RIC									RC
0.003	0.	0.	0.	0.	0.	0.	0.	0.	0.003
0.006	0.	0.	0.	0.	0.	0.	0.	0.	0.006
0.013	0.	0.	0.	0.	0.	0.	0.	0.	0.013
0.019	0.002	0.	0.	0.	0.	0.	0.	0.	0.020
0.024	0.003	0.	0.	0.	0.	0.	0.	0.	0.027
0.035	0.003	0.	0.	0.	0.	0.	0.	0.	0.038
0.036	0.003	0.	0.	0.	0.	0.	0.	0.	0.039
0.043	0.003	0.	0.	0.	0.	0.	0.	0.	0.046
0.047	0.003	0.	0.	0.	0.	0.	0.	0.	0.051
0.055	0.003	0.	0.	0.	0.	0.	0.	0.	0.058
0.062	0.003	0.	0.	0.	0.	0.	0.	0.	0.065
0.063	0.003	0.	0.	0.	0.	0.	0.	0.	0.066
0.071	0.003	0.	0.	0.	0.	0.	0.	0.	0.074
0.081	0.005	0.	0.	0.	0.	0.	0.	0.	0.086
0.094	0.005	0.	0.	0.	0.	0.	0.	0.	0.099
0.109	0.008	0.	0.	0.	0.	0.	0.	0.	0.117
0.134	0.011	0.	0.	0.	0.	0.	0.	0.	0.145
0.150	0.013	0.	0.	0.	0.	0.	0.	0.	0.163
0.184	0.018	0.	0.	0.	0.	0.	0.	0.	0.202
0.198	0.025	0.002	0.	0.	0.	0.	0.	0.	0.225
0.224	0.027	0.002	0.	0.	0.	0.	0.	0.	0.253
0.246	0.032	0.004	0.	0.	0.	0.	0.	0.	0.281
0.262	0.034	0.004	0.	0.	0.	0.	0.	0.	0.300
0.291	0.045	0.006	0.	0.	0.	0.	0.	0.	0.342
0.319	0.047	0.006	0.	0.	0.	0.	0.	0.	0.372
0.348	0.047	0.009	0.	0.	0.	0.	0.	0.	0.404
0.363	0.060	0.009	0.	0.	0.	0.	0.	0.	0.431
0.383	0.075	0.012	0.	0.	0.	0.	0.	0.	0.470
0.406	0.079	0.012	0.004	0.	0.	0.	0.	0.	0.501
0.418	0.088	0.012	0.004	0.	0.	0.	0.	0.	0.522
0.435	0.088	0.012	0.004	0.	0.	0.	0.	0.	0.540
0.445	0.100	0.012	0.004	0.	0.	0.	0.	0.	0.561
0.451	0.114	0.012	0.004	0.	0.	0.	0.	0.	0.581
0.472	0.122	0.012	0.004	0.	0.	0.	0.	0.	0.611
0.502	0.122	0.012	0.004	0.	0.	0.	0.	0.	0.641
0.510	0.122	0.012	0.004	0.	0.	0.	0.	0.	0.649
0.520	0.135	0.012	0.004	0.	0.	0.	0.	0.	0.671
0.542	0.135	0.012	0.004	0.	0.	0.	0.	0.	0.693
0.555	0.135	0.012	0.004	0.	0.	0.	0.	0.	0.705
0.555	0.135	0.035	0.004	0.	0.	0.	0.	0.	0.728
0.572	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.770
0.572	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.770
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.598	0.159	0.035	0.004	0.	0.	0.	0.	0.	0.796
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Fig. C8—Cumulative Event-Rate Page, Page 6 of the Six-Page Set Constituting M60 Tank Engine-Replacement-Rate Output

Appendix D

TECHNICAL NOTES

INTRODUCTION

In this appendix are collected brief formulations of a number of notions discussed in the body of the report.

AVAILABILITY POTENTIAL

By definition the availability potential B relative to some disability or disabilities is

$$B = 1/(1 + h\lambda),$$

where h is rate of occurrence of the disability(ies) per unit of nondisabled time, and λ is the time consumed in restoring serviceability. The word "potential" has been included in the name because both h and λ may vary with time and because the entire process is subject to chance effects. The availability potential as defined is the steady-state probability that an item selected at random from a homogeneous collection of items that fail at the constant rate k and are restored in the constant mean time λ is operable; it is the value toward which such actual probabilities in a dynamic situation tend instantaneously.

SUCCESS INDEX

The age-dependent march-success index $S(s, t)$ is defined as

$$S(s, t) = e^{-Lh(s)}/[1 + s/t\ h(s)]$$

where L = march distance
$h(s)$ = rate (per unit of distance) of occurrence of disabilities
λ = mean duration of a disability
t = vehicle age in time units
s = vehicle age in accumulated use

This formula concisely expresses the likely success of the combat vehicle in its dual role. It includes the availability potential as the measure of probability that a vehicle is available (operable) in $1/[1 + (s/t)\ h(s)]$ and the probability that an available vehicle will complete a march of length L unimpaired in $e^{-Lh(s)}$. As the product of these probabilities the success index is a measure of the probability that a vehicle is both ready and durable enough to attain a destination for engagement a distance L away. The expression $e^{-Lh(s)}$ is an approximation of $\exp[-\int_s^{s+L} h(s)\,ds]$ valid when $h(s)$ changes very little over a range L.

PIPELINE NOMOGRAM

The number of items in an overhaul pipeline at equilibrium is

$$P = Nu\lambda/S,$$

where P = number of items in the pipeline
N = number of in-use items
u = item use rate
λ = time required to restore an unserviceable item to serviceability
S = mean item use per replacement

By equilibrium is meant a situation in which N, u, λ, and S are constant. The pipeline discussed in this model has the following characteristics:

(a) It is the sole source of serviceable items.

(b) It is the sole recipient of unserviceable items.

(c) All items not in use are in it.

The equilibrium assumption has its value in that even the most changeable parameter, S, changes slowly enough that approximate equilibrium obtains for many items over periods of time on the order of a supply cycle in length.

ANNUAL "BILL" OF A BALANCED FLEET

The annual bill of a balanced n-part fleet is

$$C = \sum_{i=1}^{n} N_i u_i \left[(I_i/S_i) + M_i\right]$$

where C = the annual cost
i = one of the fleet segments
N_i = the number of vehicles in segment i
u_i = the mean annual usage of vehicles in segment i
I_i = is the cost for fleet segment i to acquire a vehicle (I_1 is the cost of a new vehicle; subsequent I_i represent rehabilitation and transportation costs associated with transferring the vehicle from segment $i-1$ to i)
S_i = the usage a vehicle accumulates during its presence in fleet segment i
M_1 = the operating cost per unit of usage of a vehicle in fleet segment i

The balanced fleet discussed is characterized by the following:

(a) There is a flow of vehicles from fleet segment $i-1$ to fleet segment i for $i = 2, 3, \ldots n$.

(b) Every vehicle makes this passage.

(c) The numbers of vehicles, usage each accumulates, and use rates in the segments are such that for each segment the inflow is exactly equal to the outflow.

(d) Only new vehicles flow into fleet segment 1.

(e) Vehicles flowing out of fleet segment n flow into salvage. Such balance implies the following relations:

$$(Nu/L)_{i-1} = (Nu/L)_i, \; i = 2, 3, \ldots n.$$

CONFIDENCE LIMITS FOR MILES PER JOB-ORDER CALCULATION

The confidence limits plotted in Figs. 19 and 20 in Chap. 4, Vol I, were derived by assuming that replacements of prime mobility parts were Bernoulli events occurring in a sequence of independent trials, where a trial was taken to be the exposure of one vehicle to 100 miles of operation. With this convention a sampled 500-mile interval contained as many as several thousand trials. Actually the confidence limits were placed on the number of events observed, and the confidence limits of the reciprocals, "miles per replacement action," were taken to be the reciprocals of the confidence limits of the number of events.

REPLACEMENT RATES AND MEAN LIVES

Replacement Rates

Raw data of the kind "at vehicle age x miles vehicle number y had its engine replaced for the ith time" were reduced to replacement rates as a function of vehicle age by the following calculation: Let the part under discussion be engines. Let N_{1i} be the number of vehicles observed during the ith age interval that had experienced no engine replacement in the previous $(i-1)$ intervals. Let M_{1i} be the number of first engine replacements observed among the N_{1i} vehicles in the ith age interval. The ratio

$$k_{1i} = M_{1i}/N_{1i}$$

was formed. In much literature k_{1i} is referred to as the hazard rate. By recursion

$$r_{1i} = k_{1i}Y_{1i}, \; Y_{11} = 1.0$$

were computed. The r_{1i} are called simply the first-engine-replacement rate. The k_{1i} are estimates of conditional probabilities of first-engine replacement—the condition being that the vehicle is known to have not yet experienced its first engine replacement. The r_{1i} are estimates of probabilities of first-engine replacement if it is not known whether the first replacement has occurred. Cumulative first replacements through n age intervals are

$$r_{1n\ \mathrm{cum}} = \sum_{i=1}^{n} r_{1i} .$$

For replacements beyond the first one an analogous approach was taken. Let N_{ji} be the number of vehicles observed during the ith age interval that had not experienced a jth engine replacement in the preceding (i-1) intervals. Let M_{ji} be the number of jth engine replacements experienced in the ith age interval by the N_{ji} vehicles. Then

$$k_{ji} = M_{ji}/N_{ji}$$

were computed, and by recursion

$$r_{ji} = k_{ji}\, Y_{ji}, \; Y_{j1} = 1.0.$$

The k_{ji}, $j \neq 1$ are not hazard rates as were the k_{1j}. They are merely a convenient device for computing r_{ji}, $j \neq 1$, which when cumulated approximate the cumulative rate derived via true hazard rates to within 0.5 percent near the median lives. Proceeding to replacement rates via hazard and quasi-hazard rates (as k_{ji}, $j \neq 1$, have been coined) removes whatever bias may exist in the censoring of the sample between age intervals i and $i+1$ of the kind "the proportion of vehicles observed in n but not in $n+1$ that had experienced jth engine replacement was $\alpha \neq r_{jn\ cum}$."

The theoretical replacement rates for major assemblies were derived by fitting a known distribution function to the first-replacement curves and assuming that subsequent assemblies would perform as well as the firsts. Let the distribution fitted to first replacements be f_s, where s is the age of the assembly measured in discrete age intervals. Let h_{2i} be the expected second-replacement distribution if the second assemblies perform the same as the originals, where i is the age of the vehicle. Such a process is called a "renewal" process, and by the renewal equation[7]

$$h_{2i} = \sum_{s=1}^{i} f_s \cdot f_{(i-s)}.$$

Similarly,

$$h_{3i} = \sum_{s=1}^{i} h_{2s} \cdot f_{(i-s)}$$

and in general

$$h_{ni} = \sum_{s=1}^{i} h_{(n-1)s} \cdot f_{(i-s)}.$$

The probability of replacement of any order is

$$h_i = \sum_{k=1}^{\infty} h_{ki}.$$

The projection of major assembly replacements from 3000 out to 5000 miles was made by deriving a linear approximation to the k_{1i} and projecting that to 5000 miles. Then, by the procedures described above, r_{1i} were computed and set equal to f_1, and h_i were computed.

Mean Lives

Mean lives quoted in the body of the report are derived by

$$\mu = \sum_{i=1}^{\infty} r_{1i} \cdot i,$$

where μ = the mean life
r_{1i} = the probability of a first replacement of the assembly in question in age interval i
i = an age interval

Appendix E

ENGINE AND TRANSMISSION REPLACEMENT RATES

Figures

INTRODUCTION

This appendix contains the basic engine and transmission replacement data that were the basis of the theoretical curves shown in Chap. 2, Vol I. The first portion of this appendix gives actual replacement rates for the total USAREUR sample as a function of mileage; the second portion gives cumulative replacement rates for the two armored divisions and for the total USAREUR sample as a function of both age and mileage.

ACTUAL ENGINE AND TRANSMISSION REPLACEMENT RATES FOR TOTAL USAREUR SAMPLE

The actual engine and transmission replacement rates from which the theoretical curves of Chap. 2, Vol I, were derived are shown in Figs. E1 to E3. The raw data and computed rates are contained in RAC unpublished documents.[5,6] A detailed description of the contents of these references is contained in App C.

The calculated rates tabulated in the references are for 100-mile increments of age. The points plotted in this section of App E are not the tabulated points but are the tabulated points smoothed by threes; i.e., a point X_i plotted for 100-mile increment i is

$$X_i = (t_{i-1} + t_i + t_{i+1})/3,$$

where the t's are the values tabulated in the RAC studies.[5,6]

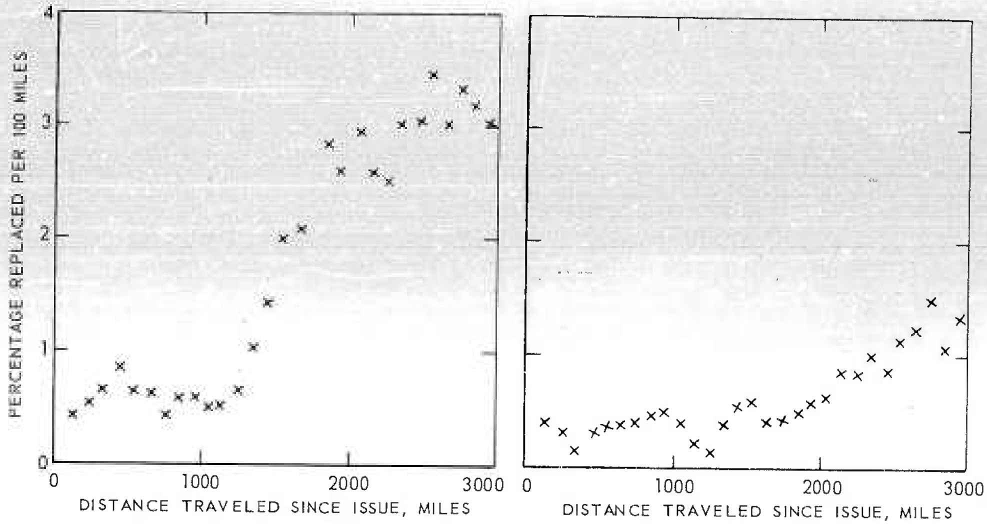
In the terms of App D in the section entitled "Replacement Rates and Mean Lives," the replacement rates plotted are simple (r), not conditional (k), rates. They are $r_i = \Sigma_{j=1}^{\infty} r_{ji}$, where j is the order of failure. Thus they are replacement rates for all orders taken together. In practice, $r_{ji} = 0, j > 3$, for the age range shown.

CUMULATIVE ENGINE AND TRANSMISSION REPLACEMENT RATES

The remaining figures of this appendix show raw cumulative replacement rates of the major assemblies discussed in this study plus those of the predecessor M48A2 tank plotted as a function of mileage and time since issue of the vehicles. Various comparisons are made. Figures E8 and E9 contain comparisons of separate plots of the 3d and 4th Armd Divs.

The effects of rate of utilization should be kept in mind when examining comparisons of vehicles or divisions, especially when their rates plotted in time are compared. In particular the divergence of the curves of Fig. E10 could be largely accounted for by the fact that the M60 tank was being used at almost twice the rate of the M48A2 tank if one held that the replacement rate depended mainly on miles since issue. Further support could be adduced to the similarity of the curves of Fig. E11. The reverse case could be made in Figs. E8 and E9, considering that the use rate of 4th Armd Div tanks was only about 81 percent that of 3d Armd Div tanks. Still other accountings are possible if it is assumed that over a range of moderate rates of use a higher use rate results in fewer replacements per mile. Such an assumption makes the mileage comparison of divisions (Fig. E9) show greater similarity and the mileage comparison of vehicles (Fig. E11) show less similarity.

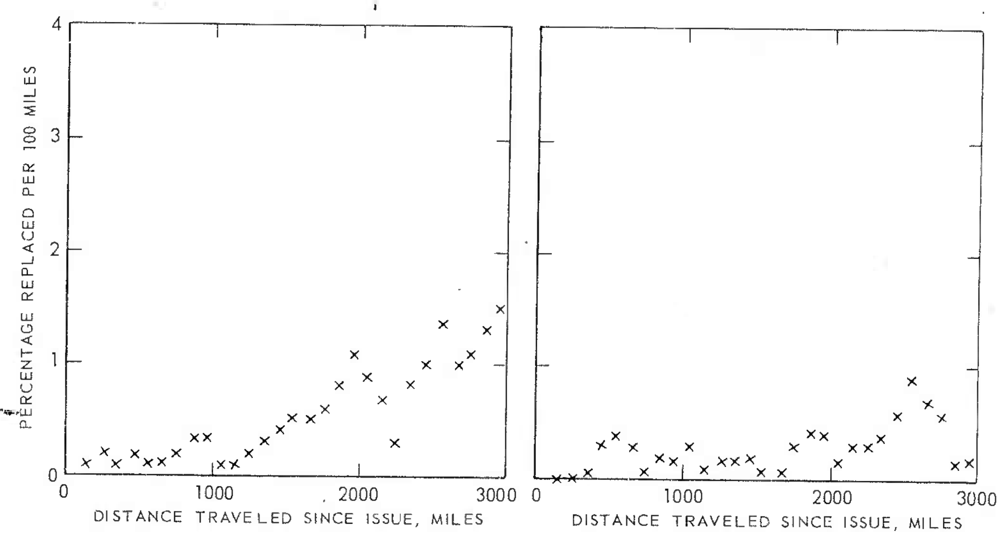
Replacement curves in Figs. E4 to E21 have been extended to the greatest age (beyond the sample average) at which the sample still included 100 vehicles. Replacement-rate curves for M88 recovery vehicle parts are exceptions to this rule because only 83 M88 recovery vehicles were observed. M88 vehicle curves stop at the average M88 vehicle age of 19 months.



a. Engine.

b. Transmission.

Fig. E1—Actual Replacement Rates of M60 Tank Major Assemblies, USAREUR Total Sample



a. Engines.

b. Transmissions.

Fig. E2—Actual Replacement Rates of M113 APC Major Assemblies, USAREUR Total Sample

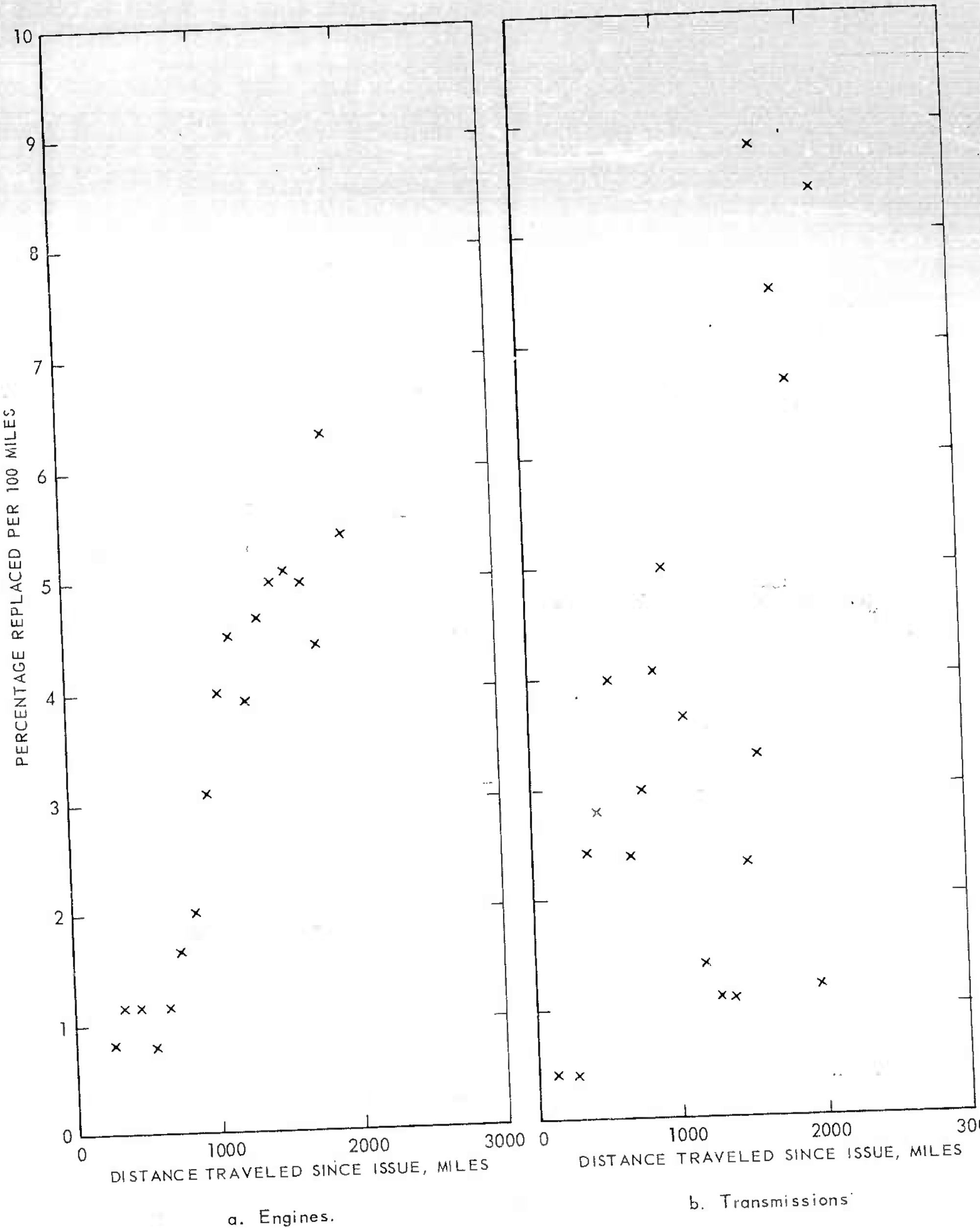


Fig. E3—Actual Replacement Rates of M88 Recovery Vehicle Major Assemblies, USAREUR Total Sample

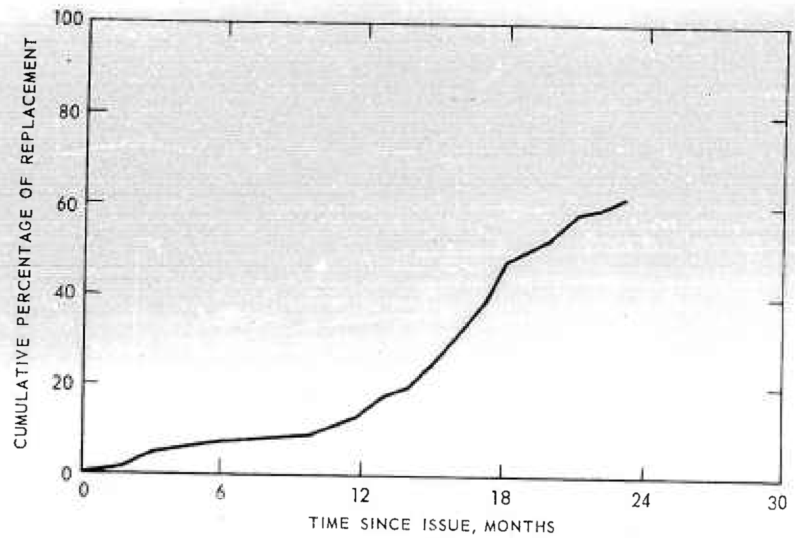


Fig. E4—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 3d Armd Div, USAREUR, as Related to Age since Issue

132 engines replaced; 30 transmissions replaced.

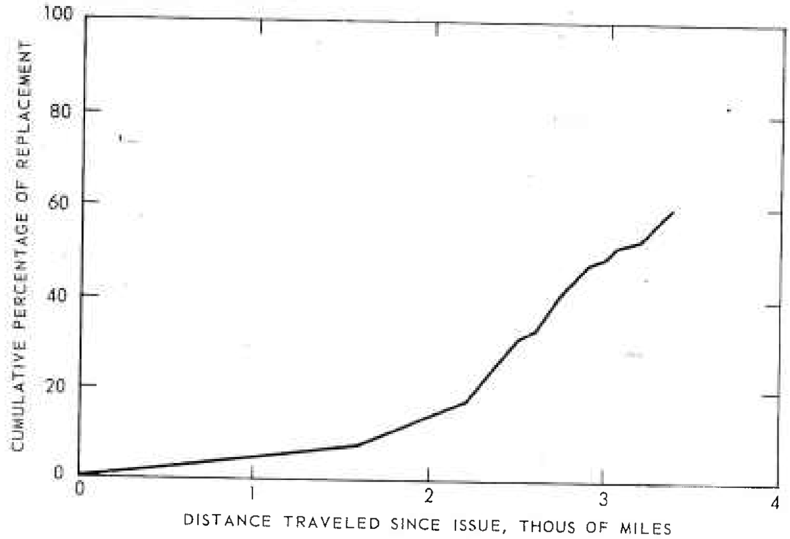


Fig. E5—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 3d Armd Div, USAREUR, as Related to Distance Traveled since Issue

132 engines replaced; 30 transmissions replaced.

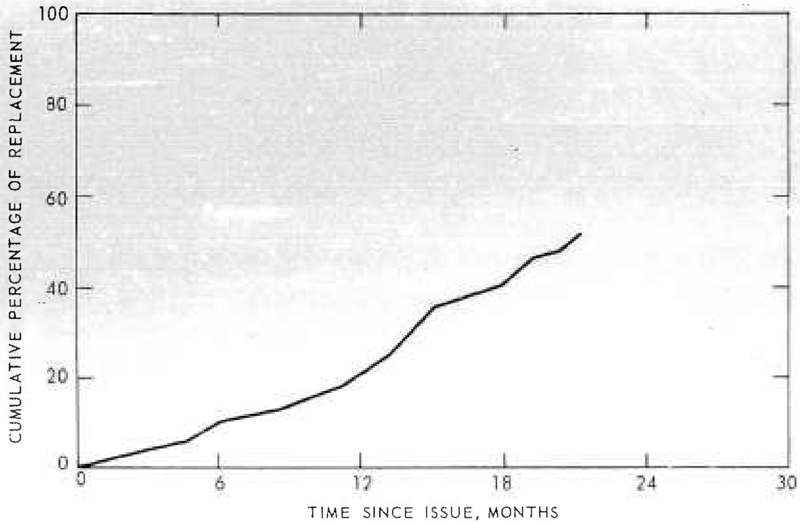


Fig. E6—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 4th Armd Div, USAREUR, as Related to Age since Issue

111 engines replaced; 48 transmissions replaced.

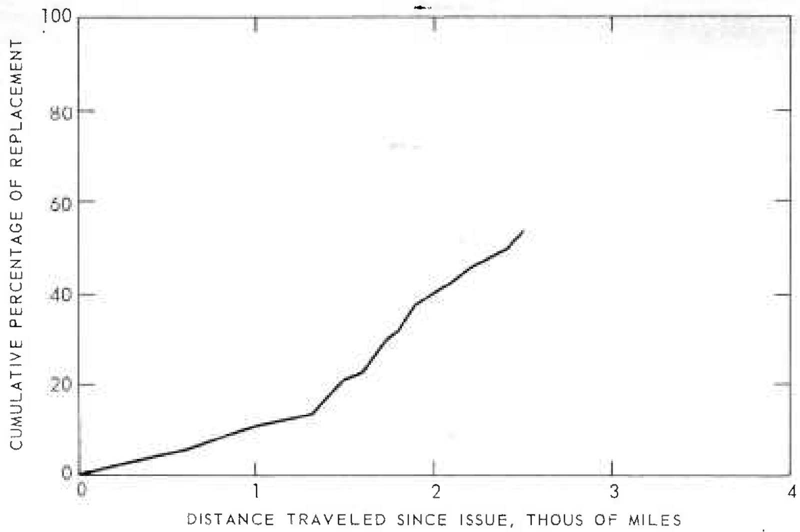


Fig. E7—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 4th Armd Div, USAREUR, as Related to Distance Traveled since Issue

111 engines replaced; 48 transmissions replaced.

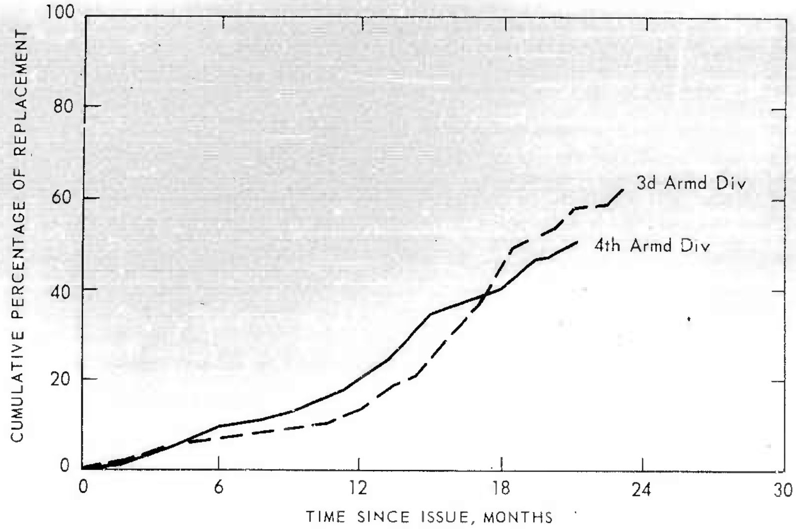


Fig. E8—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 3d and 4th Armd Divs, USAREUR, as Related to Age since Issue

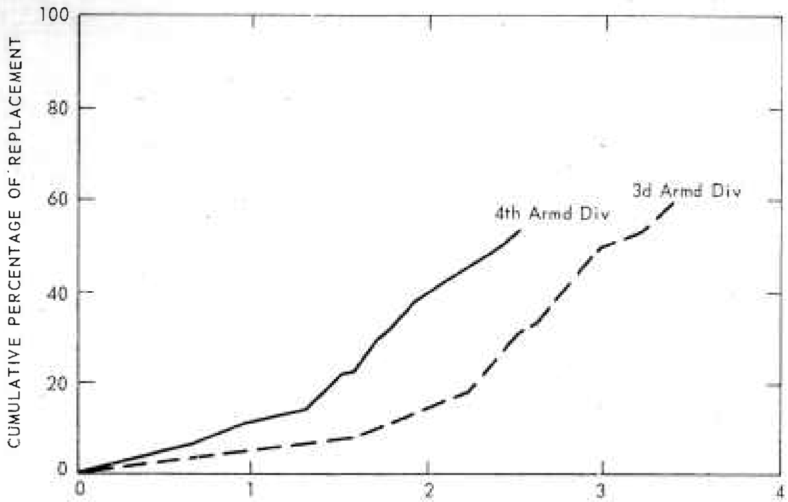


Fig. E9—Cumulative Replacement Rate of M60 Tank Engines and Transmissions Combined, 3d and 4th Armd Divs, USAREUR, as Related to Distance Traveled since Issue

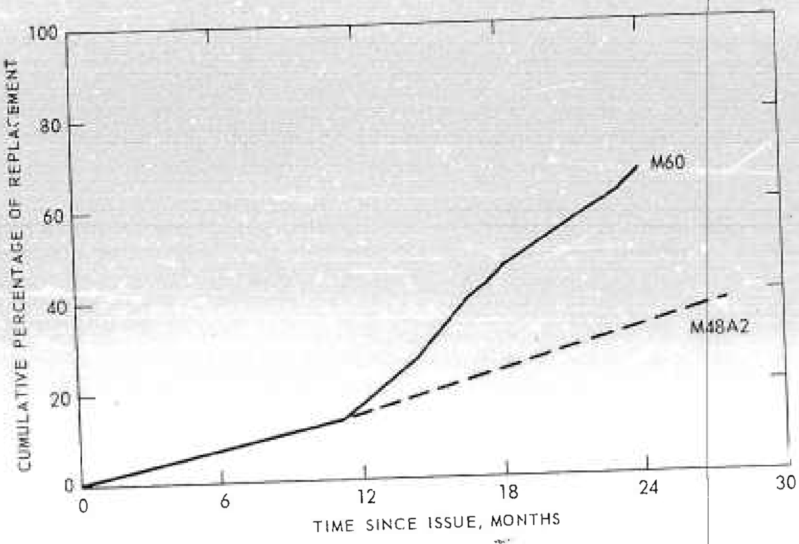


Fig. E10—Comparison of Cumulative Replacement Rate of M60 and M48A2 Tank Engines and Transmissions Combined, as Related to Age since Issue, USAREUR Total Sample

286 M60 engines replaced; 91 M60 transmissions replaced.

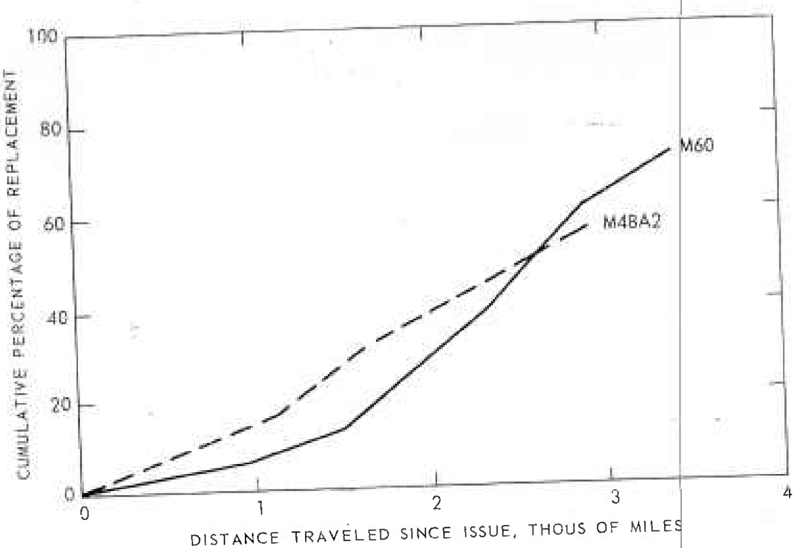


Fig. E11—Comparison of Cumulative Replacement Rate of M60 and M48A2 Tank Engines and Transmissions Combined, as Related to Distance Traveled since Issue, USAREUR Total Sample

286 M60 engines replaced; 91 M60 transmissions replaced.

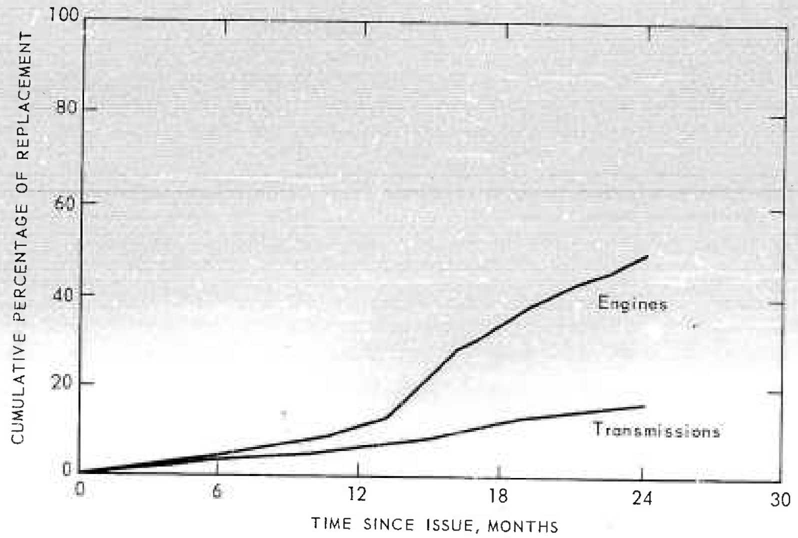


Fig. E12—Comparison of Cumulative Replacement Rates for M60 Tank Engines and Transmissions, as Related to Age since Issue, USAREUR Total Sample

286 engines replaced; 91 transmissions replaced.

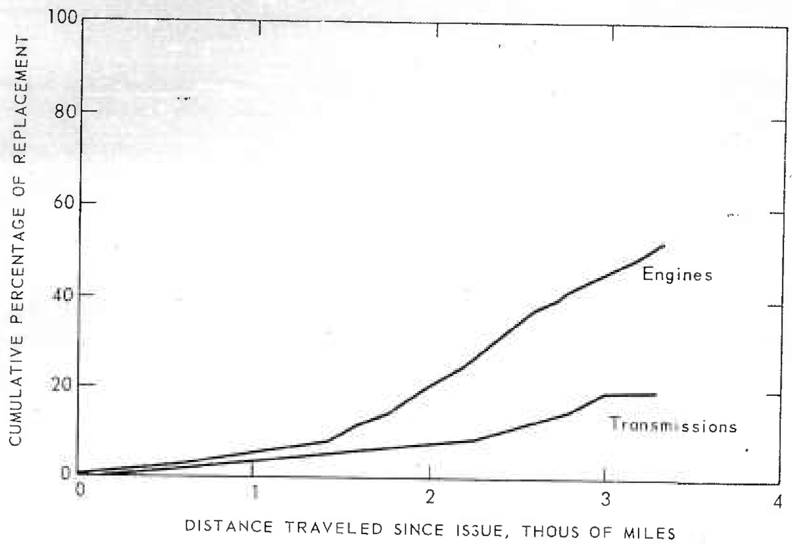


Fig. E13—Comparison of Cumulative Replacement Rates for M60 Tank Engines and Transmissions, as Related to Age since Issue, USAREUR Total Sample

286 engines replaced; 91 transmissions replaced.

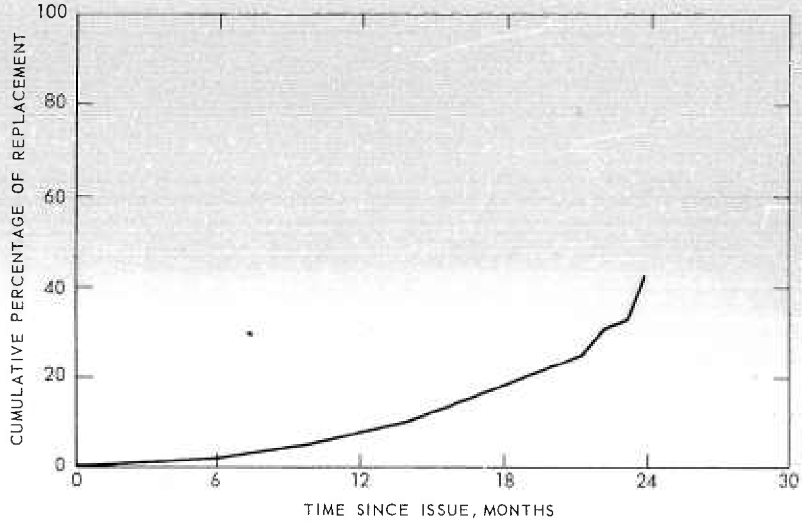


Fig. E14—Cumulative Replacement Rate of M113 APC Engines and Transmissions Combined, as Related to Age since Issue, USAREUR Total Sample

97 engines replaced; 55 transmissions replaced.

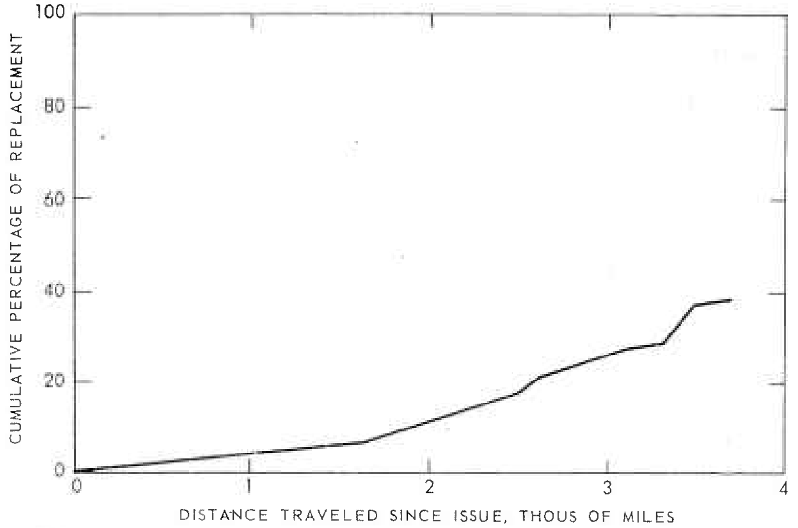


Fig. E15—Cumulative Replacement Rate of M113 APC Engines and Transmissions Combined, as Related to Distance Traveled since Issue, USAREUR Total Sample

97 engines replaced; 55 transmissions replaced.

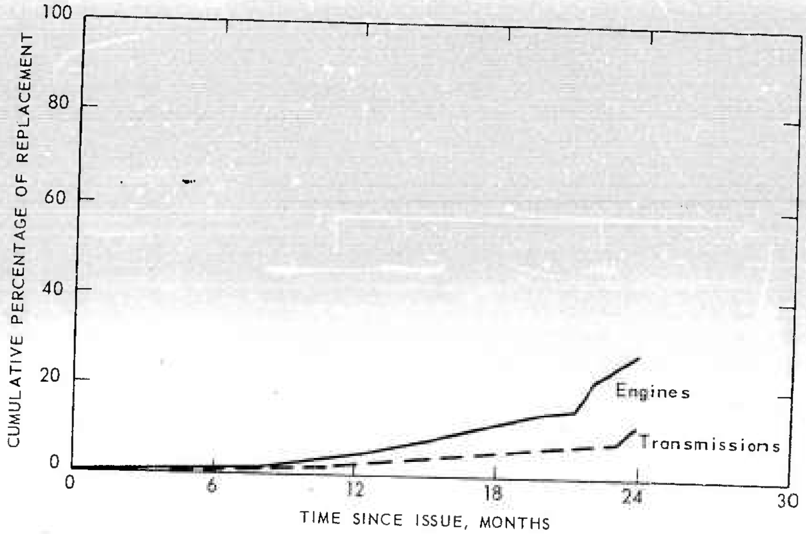


Fig. E16—Comparison of Cumulative Replacement Rates for M113 APC Engines and Transmissions, as Related to Age since Issue, USAREUR Total Sample

97 engines replaced; 55 transmissions replaced.

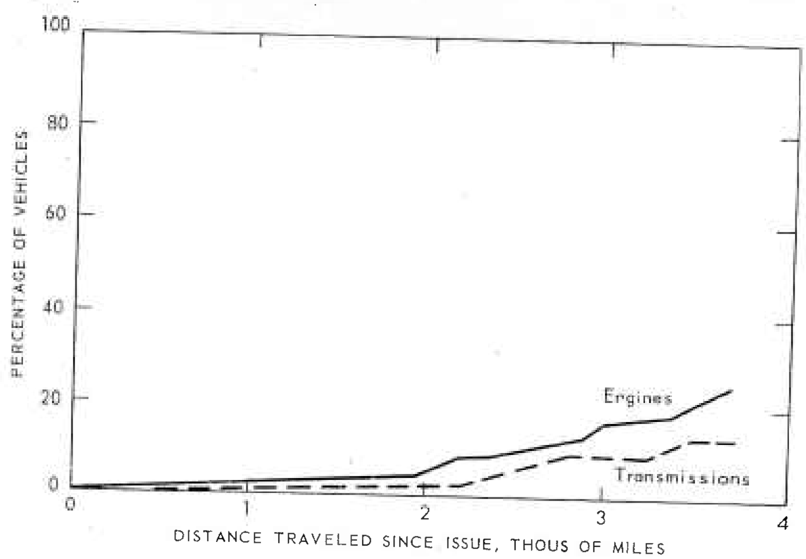


Fig. E17—Comparison of Cumulative Replacement Rates for M113 APC Engines and Transmissions, as Related to Distance Traveled since Issue, USAREUR Total Sample

97 engines replaced; 55 transmissions replaced.

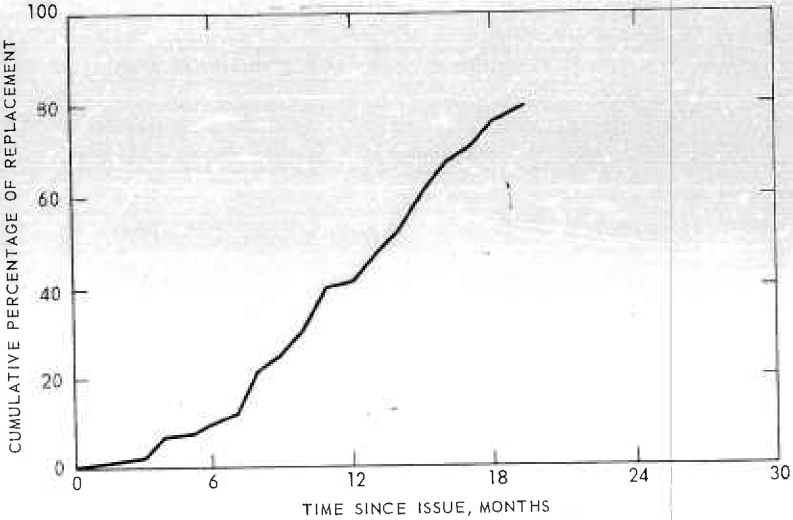


Fig. E18—Cumulative Replacement Rate of M88 Recovery Vehicle Engines and Transmissions Combined, as Related to Age since Issue, USAREUR Total Sample

31 engines replaced; 37 transmissions replaced.

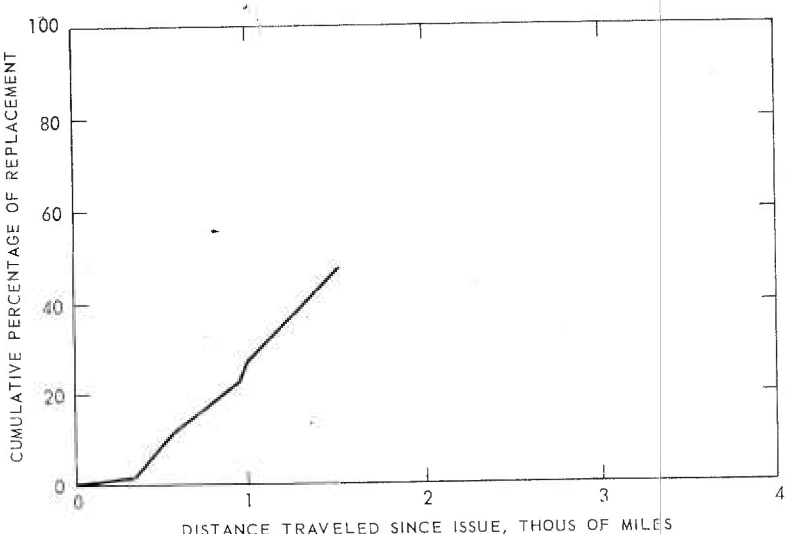


Fig. E19—Cumulative Replacement Rate of M88 Recovery Vehicle Engines and Transmissions Combined, as Related to Distance Traveled since Issue, USAREUR Total Sample

31 engines replaced; 37 transmissions replaced.

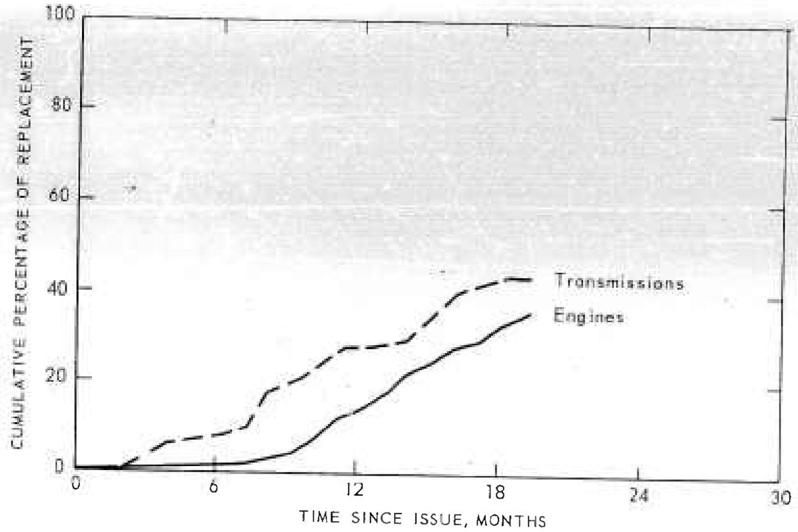


Fig. E20—Comparison of Cumulative Replacement Rates for M88 Recovery Vehicle Engines and Transmissions, as Related to Age since Issue, USAREUR Total Sample

31 engines replaced; 37 transmissions replaced.

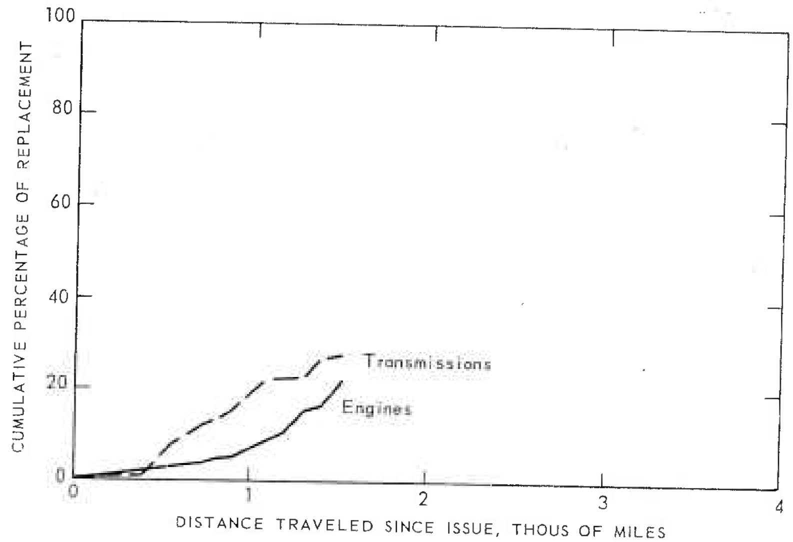


Fig. E21—Comparison of Cumulative Replacement Rates for M88 Recovery Vehicle Engines and Transmissions, as Related to Distance Traveled since Issue, USAREUR Total Sample

31 engines replaced; 37 transmissions replaced.

Appendix F

ANALYSIS OF THE RECORDED MAINTENANCE HISTORY OF 17 M60 TANKS SELECTED TO TEST THEIR ENDURANCE UNDER CONTINUAL USE

B Co, 1st Bn, 33d Armor, 3d Armd Div

Tables

INTRODUCTION

Shortly after the M60 tanks were assigned to units of the Seventh Army, USAREUR, Deputy Chief of Staff for Logistics (DCSLOG) designated the 17 tanks of B Co, 1st Bn, 33d Armor, 3d Armd Div, as test vehicles in a study of the endurance of the M60 tank under continual use. During this test only the normal maintenance support was to be provided. DCSLOG then requested that RAC collect the pertinent data, develop a detailed maintenance history of these tanks, and analyze these histories in terms of endurance limits.

It is recognized that this special study has limited value because the number of tanks in the sample is too small to provide a suitable statistical basis. It is, however, the most complete history to date of the maintenance requirements for tanks that have experienced more than 5000 miles of continual use.

MAINTENANCE HISTORY

Introduction

A comprehensive study of several types of newly issued tracked vehicles was undertaken by RAC in 1962. The findings of this study are presented in this memorandum. Because it is based on a very limited sample this memorandum cannot be used as a basis for predicting the maintenance requirements of a fleet of several thousand tanks. Although the number of tanks constituting the sample is small, the data collected on them represent the most complete maintenance history ever developed on tanks that have an average of nearly 6000 miles of utilization. This appendix is intended to show the maintenance history of 17 tanks by presenting what actions were performed in relation to miles of operation, what echelon of maintenance performed the work, the labor man-hours involved, and the cost of parts replacements. In an effort to make the data more meaningful some interpretations and comparisons with data on other tanks are made.

For approximately 2 years, maintenance and operational data were collected on a large sample of these vehicles assigned to battalion-sized combat units stationed in Germany. Five of these units were designated by RAC as "depth units," i.e., units from which all pertinent maintenance data would be collected in as detailed a form as possible for the three types of vehicles. The 1st Bn, 33d Armor, 3d Armd Div, was selected as a "depth unit" because it was the first armored battalion in USAREUR to receive its complement of M60 tanks. B Co of this battalion was subsequently designated by DCSLOG as the unit to test the endurance of the M60 tank. Relative to this test, DCSLOG requested that RAC prepare a paper based on the maintenance data collected on the tanks from this company.

Since it was the first battalion-sized unit in the Seventh Army to receive its complement of the new tanks the 1st Bn, 33d Armor was immediately subjected to close observation by personnel from various interested agencies including RAC. Because of this surveillance some unavoidable bias on the plus side is probably reflected in the maintenance data collected from the unit. With the exception of B Co the collection of data from the battalion was completed as of 30 Sep 1963; collection of B Co data continued through June 1964. Although B Co's tanks were still in operation in Dec 1964, most of the other tanks in the battalion have been turned in for depot repair.

With few exceptions the new tanks were assigned to the battalion over a 3-day period in May 1961. B Co received its complement of M60 tanks on 15 May 1961. About a month after issue one of the original tanks was replaced. This replacement tank was in turn replaced but it had logged over 4000 miles before this occurred. The maintenance data related to this vehicle have been retained and included in calculations performed through its last mileage of approximately 4200 miles. The maintenance and operation data collected on B Co's M60 tanks represent a continuous maintenance history covering 613 tank-months and 97,000 tank-miles. On 30 June 1964 the original tanks assigned to the company had an average of 5707 miles per tank. The variation around this average end-mileage ranged from a low of 4888 miles to a high of 6077 miles. During the 30 months for which operation data were available the tank utilization per month averaged 162 miles. The range of average utilization for these tanks was from 25 to 312 miles per month. The average miles per month were derived from the data collected from the Equipment-Daily-Monthly Log (DA Form 2408-1) of the Army Equipment Records System (TAERS). This is one of the several forms contained in the TAERS logbook, which is placed on vehicles under this system for the purpose of collecting pertinent maintenance and operation information. This system was introduced in the 3d Armd Div in January 1962, and the collection of monthly mileage data began at that time.

In addition to the TAERS logbook, information was collected from the Organizational Equipment File (DA Form 478), the Current Work File (CWF), Document Register for Supply Actions (DA Form 2064), and Maintenance Request (DA Form 2407). For ease and efficiency the information collected was transferred to electronic accounting machine (EAM) cards. This facilitated the elimination of duplicate data, development of part replacement rates, and the numerous information sorts required for an analysis.

Parts Replacement

Between May 1961 and June 1964 the records show that 1463 replacement actions were performed on B Co's tanks. A replacement action can involve the replacement of one or more parts with the same Federal Stock Number (FSN) at the same time; e.g., one replacement action could mean the replacement of 1 track-shoe assembly or 162 track-shoe assemblies. Table F1 shows the total number of replacement actions, FSNs used, parts used, and total cost of the parts replaced.

In the absence of actual overhaul cost, engines and transmissions were costed on the same basis as that used for crediting an economically reparable item by the Stock Fund to the Operation and Maintenance Army fund. The credit allowed on such items is 70 percent leaving a 30 percent charge for the item. This method of costing has been used to develop a price for major assembly replacements. All other parts replaced have been costed at list price.

TABLE F1

Maintenance Replacement Activity

(B Co, 1st Bn, 33d Armor)

Replacement actions	FSNs used	Parts used	Parts cost[a]
1463	418	11,777	$415,451

[a]Engine and transmission at 30 percent of list price.

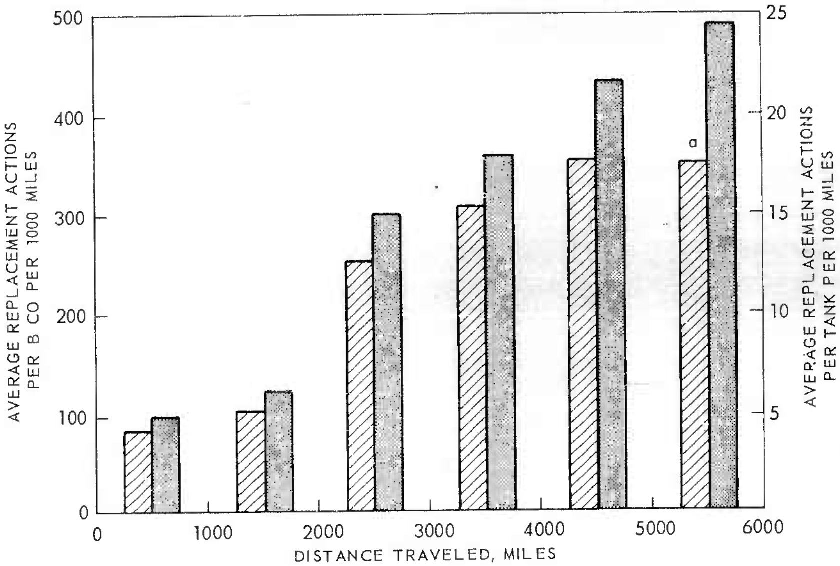


Fig. F1—Frequency of Parts-Replacement Actions per M60 Tank of B Co, 1st Bn, 33d Armor

[a] 15 Tanks   Company   Tanks

A graphic representation of B Co's tank-parts replacement activities by 1000-mile increments is shown in Fig. F1. The scale on the left-hand axis of the chart shows the number of replacement actions per B Co per 1000 miles; the scale on the right-hand axis shows the average replacement actions per tank per 1000 miles. From this chart it can be seen that, as the tanks aged in miles, replacement activity increased from 83 actions for the 17 tanks in the first 1000-mile interval to 350 in the sixth 1000-mile interval. It also shows that the average number of replacement actions per tank in the sixth 1000-mile interval more than quadrupled the number that occurred in the first 1000-mile interval. Miles per replacement action decreased from 205 in the first 1000-mile interval to 43 miles in the sixth 1000-mile interval. This is indicative of the loss in reliability and availability that B Co's tanks are experiencing as their age in mileage increases. It will also be noted that although maintenance activity involving parts replacement increases as mileage increases, it increases at a slower rate.

In Fig. F2 a comparison is made of the parts-replacement activity per tank of B Co with the battalion less B Co and the total battalion. During the first 1000 miles of operation the replacement activity of B Co's tanks was about the same as the rest of the tanks in the battalion. Over the following 2000 miles of operation, B Co's tanks performed somewhat better than the other tanks in terms of parts replacement. As illustrated in previous figures, this figure also shows the pronounced increase in replacement activity that takes place in the third 1000-mile interval. It will be noted in the fourth and fifth 1000-mile intervals that the battalion less B Co shows a decrease in replacement activity. The recorded replacement data provide no indication as to why this decrease in activity took place. It may have been caused in part by the anticipated turn-in of these tanks for overhaul. It is also possible that maintenance work was performed but not actually recorded.

Figure F3 presents the total quantity of parts replaced on the battalion's tanks and the average number of parts replaced per tank by B Co and the battalion less B Co over the several 1000-mile intervals. This chart is based on a count of the individual parts replaced as identified by FSNs. For example, replacement of a complete set of tank track would be recorded as 162 track-shoe assemblies, FSN 2530-337-6969, and such recordings were counted as 162 parts. When the previous statement is related to the mean track life, which for this battalion was found to be 2205 miles, it can be deduced from the figure what degree of impact track replacement had on the number of parts replaced in the third 1000-mile interval. The chart further provides a good indication of the volume of parts required to support a battalion of tanks during approximately 2 years and 290,000 miles of utilization.

The parts (identified by FSN and nomenclature) having the highest frequency of replacement demands for B Co's tanks are shown in Table F2. For comparative purposes the frequency of replacement of these parts is also shown for the 1st Bn, 33d Armor, less B Co and the 2d Bn, 37th Armor. From this table it will be noted that parts related to the suspension system have the highest incidence of replacement. Only parts that had been demanded in 15 or more replacement actions were included in the list.

B Co's maintenance records show that 11,777 parts have been replaced. When these parts are identified by FSN it is found that these 11,777 parts represented 418 stock numbers. An analysis of parts replacements in relation to FSNs is presented in Fig. F4. From this chart it can be seen that 57 percent or 238 FSNs were replaced once whereas only 17 percent or 63 FSNs were replaced five times or more. Of the later FSNs, 23 are related to the parts nomenclature listed in Table F2. Starters and road wheels are identified by two individual FSNs each. The distribution shown in Fig. F4 is very similar to that of the battalion as a whole and to that found for the 2d Bn, 37th Armor,

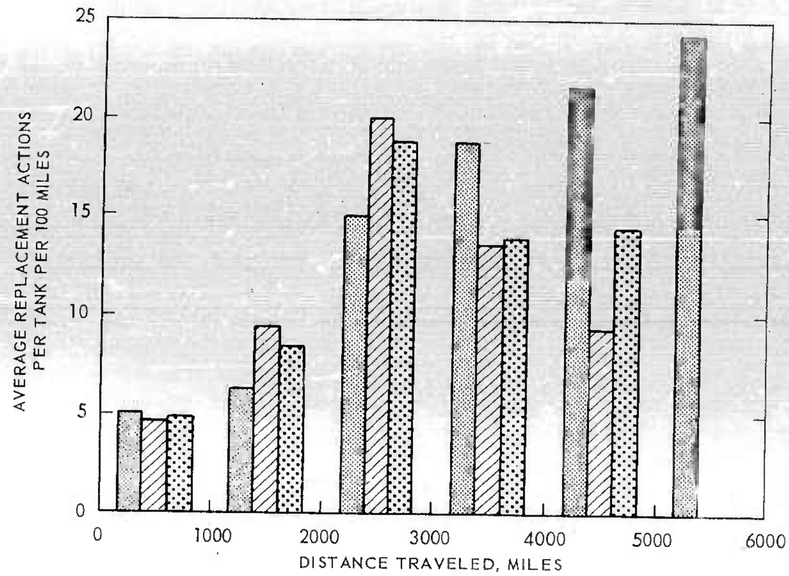


Fig. F2—Comparative Replacement Actions per M60 Tank of B Co; 1st Bn, 33d Armor less B Co; and 1st Bn, 33d Armor

B Co | 1st Bn, 33d Armor less B Co | 1st Bn, 33d Armor

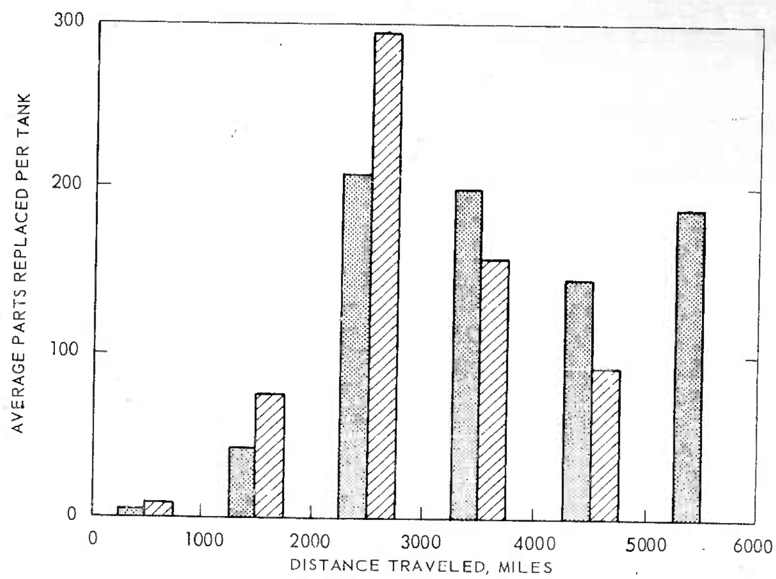


Fig. F3—Comparison of the Average Parts Replaced per M60 Tank of B Co and 1st Bn, 33d Armor, less B Co

Total parts replaced, 41,623.

B Co | 1st Bn, 33d Armor less B Co

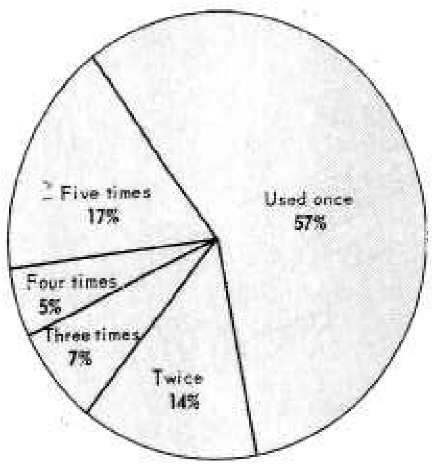


Fig. F4—Distribution of the 418 FSNs Used for M60 Tanks by B Co, 1st Bn, 33d Armor

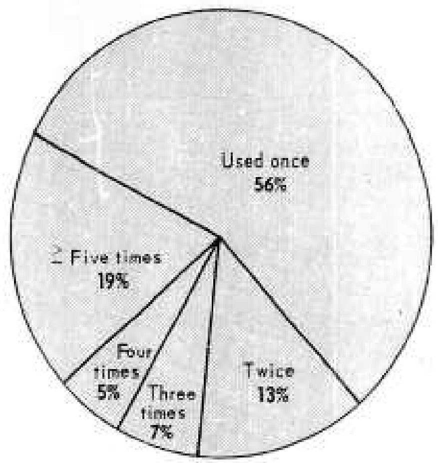


Fig. F5—Distribution of the 931 FSNs Used for M60 Tanks by 1st Bn, 33d Armor

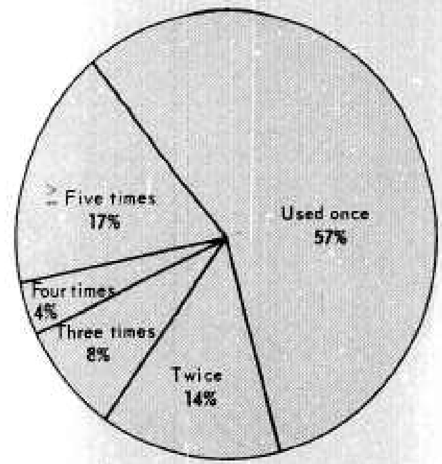


Fig. F6—Distribution of the 612 FSNs Used for M60 Tanks by 2d Bn, 37th Armor

4th Armd Div. The distributions of the FSNs used by the 1st Bn, 33d Armor, and the 2d Bn, 37th Armor, are presented in Figs. F5 and F6 respectively. Although the distributions shown in these figures are quite similar when they are considered in relation to Table F2, it can readily be seen that a stockage list based on any one of these units would not provide an effective list for either of other units. (A list of the parts replaced, identified by FSN, appears in Table F3.)

TABLE F2

Federal Stock Numbers Most Frequently Used in Replacement Actions in B Co Compared to Their Frequency of Replacement in the 1st Bn, 33d Armor, less B Co and the 2d Bn, 37th Armor

FSN	Nomenclature	Replacement actions per 1000 miles		
		B Co[a]	1st Bn, 33d Armor, less B Co[b]	2d Bn, 37th Armor[c]
1220-675-1173	Computer	0.154	0.018	0.007
2815-679-4963	Engine	0.165	0.078	0.188
6105-873-5379	Motor, blower	0.154	0.128	0.029
2530-784-9293	Plate	0.154	0.037	—
2920-710-1752 2920-796-2616	Starter	0.165	0.100	0.442
1240-676-2178	Telescope M105C	0.165	0.005	0.014
2530-602-5741	Shim	0.175	0.073	0.051
2530-678-3159	Retainer, road wheel	0.186	0.201	0.058
2540-711-0661	Seal	0.186	0.164	0.051
2910-678-3490	Filter, fuel	0.196	0.151	—
2590-693-3604	Seal, hatch	0.196	—	—
2540-678-9030	Seat	0.196	0.123	—
5315-769-9609	Pin	0.237	0.256	0.181
6240-019-0877	Bulb	0.258	0.119	0.59
2530-318-0229	Sprocket, F. O.	0.320	0.178	0.290
2530-602-5740	Pin assembly	0.330	0.128	0.116
6240-368-4972	Head lamp	0.371	0.151	0.181
2530-678-3161	Excluder, road wheel	0.381	0.379	0.261
5330-678-4753	Seal, arm assembly	0.381	0.429	0.428
2530-678-4133 2530-784-9292	Wheel, road	0.433	0.301	0.239
2530-337-6969	Shoe, track assembly	0.526	0.452	0.341

[a]5700 average miles/tank.
[b]3800 average miles/tank.
[c]2500 average miles/tank.

The replacement rates of a number of items selected because of their high-dollar cost and importance to tank operation are shown in following figures. B Co's tank-engine replacement rate is shown in Fig. F7, where it is compared with the engine replacement rate of the battalion less B Co and to the rate of the total tank sample (640 tanks). From the comparison of B Co with the battalion less B Co it can be seen that the company's tanks over the first 100 miles of operation experienced a higher proportion of replacements than did the other tanks in the battalion. If these early replacements are ignored it will be noted that the replacement rate of the B Co tanks approximates

TABLE F3

B Co, 1st Bn, 33d Armor, M60 Tanks Recorded Replacement Parts Identified by FSN

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Pin, Lock	0000 000 0011*	1		1											1
Reticle	0000 000 0018*	1		1											2
Seal, AC	0000 000 0021*	1			1										2
Seal	0000 000 0023*	1				1									2
Spacer	0000 140 4678*	1					1								-
Retainer	0000 740 4650*	1					1								-
Rod	0000 740 4674*	1					1								4
G. C. Assy	0000 797 3630*	1					1								-
Bolt	0000 838 2360*	1						1							-
Wire	0000 876 1554*	1							1						2
AC Assy	0001 086 3539*	1		1											3
Tank, Fuel	0001 087 0950*	1			1										-
Guard	1005 399 6697	2					2								.5
Lock Cup	1005 399 6736	1							1						-
Grip	1005 399 6819	1											1		.5
Spring	1005 501 3516	1							1						-
Spring	1005 501 3691	1							1						-
Slide	1005 535 1220	1							1						-
Pin	1005 587 0292	1			1										-
Pad. Assy	1005 591 2966	2												2	1
Extractor	1005 600 8959	1										1			-
Extension	1005 600 8976	1										1			-
Screw	1005 609 0353	3	3												-
Pin	1005 610 0302	1												1	-
	1005 650 8237	1										1			-
Washer	1005 690 0301	1												1	-
Slide	1005 690 0304	1							1						-
	1005 690 0315	2						2							-
	1005 690 0318	1										1			-
Belt. Assy	1005 690 0324	1										1			1
Spring	1005 690 0568	3									1			2	-
Pin	1005 707 0291	2											1	1	.5
Pin	1005 707 0292	2							1					1	-

*Recognized as not being FSN but included as recorded numbers.

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions												Average Recorded Man Hours
			0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	
Plunger	1005 715 7693	2											1	1	-
Pin	1005 731 0080	1										1			-
	1005 733 4759	1										1			-
Cover	1005 746 6272	2												2	1
Spring	1005 764 0843	1												1	-
Spring	1005 769 0839	1												1	.5
Shield	1005 770 5862	2												2	.5
Bolt	1005 857 0023	1												1	.5
Brush	1015 615 7208	1							1						-
No-Back	1015 624 6643	9				8	1								1
Pin	1015 678 4278	1										1			.5
Extractor	1015 678 4296	2				1	1								-
Extractor	1015 678 4297	3					2							1	.5
Pin	1015 678 4302	1									1				-
Extractor	1015 678 4308	1	1												1
Retractor	1015 678 4304	4		2						1		1			.5
Ring	1015 678 4314	4									4				.5
Key	1015 678 4315	3								1	2				-
Shell	1015 833 8566	1								1					-
Switch	1055 399 6667	1												1	.5
Pin	1157 070 2921	1												1	.5
Computer	1220 675 1173	15	2	13											1
Computer	1220 856 9454	1												1	-
Headrest	1240 346 8071	1											1		-
Switch	1240 535 6925	1	1												-
Headrest	1240 61(7758	9					2			2	4			1	.5
Headrest	1240 612 1436	7							1	1	2		1	2	1
Range Finder	1240 676 2173	1		1											-
Telescope M105C	1240 676 2178	16	3	13											1
Spring	1665 727 8850	1												1	-
Spring	1885 784 0839	1												1	1
	1990 678 4678	1												1	1
Kit, Heater	2320 656 2314	2								1			1		.5
Bushing	2320 692 9104	1												1	-
Regulator	2426 338 4260	1										1			2
	2453 055 2741	1											1		-
Spring	2510 321 5998	1									1				-

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Spring	2510 321 5999	1									1				-
Retainer	2510 560 2451	2												2	1
Box	2510 631 2896	1												1	-
Roller Bearing	2510 678 3476	4								1	3				2
Cushion	2510 690 1172	3				1					2				1
Hose	2510 691 4460	1						1							-
Seal	2510 692 8913	4		1				2			1				-
Clamp	2510 795 2788	8							1	1	6				-
Back Rest	2510 798 5127	1												1	1
Actuator Assy	2520 332 0072	2				1					1				3
Spring	2520 332 0078	4								3	1				-
Shim	2520 332 0088	1									1				-
	2520 559 1570	1								1					-
Gasket	2520 561 9965	6					1		1		1	2		1	4
Adapter	2520 563 5440	2								1		1			-
Accumulator	2520 565 3199	1						1							4
Coupling	2520 571 8120	9				4		3	1					1	1.5
Transmission	2520 670 5379	1					1								8
Transmission	2520 774 8333	3										1	1	1	8
Transmitter	2520 673 2973	3									1		1	1	.5
Valve, Transmission	2520 692 4909	3					3								2.5
Shaft, Tach	2520 752 7479	2				1								1	2
Gasket	2520 770 7232	14					3	3	1	1	2	2	2		-
Gasket	2520 776 7831	1							1						-
Wheel	2530 200 1335	1									1				-
Sprocket	2530 313 0229	31				1	2	14	1			2	2	9	13
Shoe, Track	2530 337 6969	51				2	11	5	7	9	8	4	1	4	17
Lock	2530 353 2436	1											1		-
Bracket	2530 475 6331	1						1							-
Pin	2530 506 7644	1								1					-
Kit, Center Guide	2530 570 0189	2								1	1				-
Bearing	2530 599 9070	1											1		-
Linkage	2530 602 5738	6						1		1		1	2	1	1
Linkage	2530 602 5739	6				2					2		1	1	3
Pin Assy	2530 602 5740	32		4	1	4	1	5		4	6	1	1	2	3.5
Shim	2530 602 5741	17		4		1				5	6	1			-
Linkage	2530 602 5790	1								1					-
Kit, Tk Conn	2530 608 2269	5							1	1		1	1	1	1

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Pin	2530 652 5740	1											1		-
Axle	2530 678 3017	1										1			-
Plate	2530 678 3028	1												1	1
Arm Assy	2530 678 3147	4					1	1			1		1		6
Arm Assy	2530 678 3148	6									4			2	7.5
Arm	2530 678 3152	1											1		-
Arm	2530 678 3157	2					1				1				-
Retainer	2530 678 3159	18					5		1	4	6	1		1	3.5
Excluder	2530 678 3160	1								1					.5
Excluder, R.W.	2530 678 3161	37				1	8	9	1	4	4		2	8	7.0
Plate	2530 678 4130	4					1			1	2				-
Hub	2530 678 4131	1			1										5
Wheel RD	2530 678 4133	8			1		1			1	3		2		1.5
Wheel RD	2530 784 9292	34					1	1	2	4	10		3	13	3
Wheel, Trk Sup. Rlr	2530 678 4156	9	1								4		3	1	-
Plate	2530 678 4157	9							1	1	4	1	2		-
Excluder	2530 679 3161	2												2	1
Bushing	2530 692 9104	14						1	3	4	3		1	2	7
Bearing	2530 699 9070	1											1		2
Spring	2530 706 2317	2									2				-
Hub Sprocket	2530 736 4134	6						2	1			1	1	1	3
Hub	2530 736 4260	1								1					2
Hub	2530 736 4672	2												2	1.5
Plate	2530 784 9293	15				1	2			5	1		1	5	-
Arm	2530 871 2854	3											1	2	4
Pin	2536 602 5746	1												1	-
Spacer	2540 039 8744	1												1	.5
Switch	2540 049 4199	1												1	-
Spring	2540 565 3440	1												1	.5
Handle	2540 631 2896	5			2	1		1		1					-
Bushing	2540 678 4157	1									1				-
Strap	2540 678 4170	1												1	.5
Insulation	2540 678 4215	5					1	2			2				-
Spring	2540 678 6769	1					1								-
Seat	2540 678 6770	1												1	.5
Seat	2540 678 9030	19					3	2		4	8	2			.5
Absorber, Shock	2540 690 2756	9	1					3	2	1	1		1		-

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Seal	2540 692 8913	4							2				2		-
Retainer	2540 692 9137	1												1	1
Pump Assy	2540 692 9218	3					1						1	1	-
Hook	2540 706 8219	1												1	.5
Back Rest	2540 707 3970	11						3		4	3	1			.5
Seal	2540 766 1935	1								1					-
Heater, Personnel	2540 769 0823	12				2	3	3		1	2			1	1
Seal	2540 711 0661	18			1	2	1	2	4	4	4				1
Cover	2540 711 0663	1								1					-
Seal	2540 711 0668	4						4							-
	2540 775 0661	1										1			.5
Kit	2540 785 6359	1												1	1
Seal	2540 854 4460	4									3	1			.5
	2590 025 3676	1						1							-
	2590 643 3490	1			1										1
Gasket	2590 678 3474	1				1									-
Seal	2590 693 3490	1				1									1
Seal	2590 693 3604	19						9	6	2	2				-
Guard	2590 711 9364	4								1	3				-
Switch	2590 735 4063	2							2						-
Spring	2590 740 1680	1												1	1
Pipe	2770 678 3264	1												1	-
Nozzle	2610 707 8784	1						1							10
Manifold	2815 678 3213	1												1	-
Manifold	2815 678 3214	4				2	1							1	8
Manifold	2815 678 3215	2											1	1	-
Gasket	2815 678 3216	1									1				-
Engine	2815 679 4963	15	2				3	1	3	2	1	1	1	1	14
Pump, Inj	2910 064 6265	1												1	4
Pump, Inj	2910 473 8003	4		1		1				1	1				15.5
Pump, Inj	2910 783 7063	1				1									6
Tank, Fuel	2910 447 9942	4				1			2		1				10.5
Gasket	2910 678 3247	1											1		.5
Gasket	2910 678 3248	3					1			1				1	-
Filter	2910 678 3282	2						1			1				-
Gasket	2910 678 3298	4					1	1	1				1		.5
Nozzle	2910 678 3300	3									2		1		8
Filter, Fuel	2910 678 3490	19					6	2	4	1	5			1	1.5

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions												Average Recorded Man Hours
			0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	
Pump	2910 678 4673	3									2			1	5
Gasket	2910 678 5369	1						1							-
Gasket	2910 678 5669	1						1							-
	2910 679 1466	1										1			1
Hose	2910 707 3958	1												1	-
Seal	2910 707 8782	1						1							-
Nozzle	2910 707 8784	1						1							16
Pump Assy	2910 765 9594	8								1	4			3	-
Valve	2910 785 6362	1									1				-
	2910 807 6812	1											1		-
Regulator	2920 335 4360	1							1						-
Regulator	2920 338 4264	11	1			1		1		5	1	1	1		1.5
Relay	2920 445 0865	1	1												-
Relay	2920 678 4254	2	1			1									1
Starter	2920 710 1752	12			2	1		2		3			4		6.5
Starter	2920 796 2616	4	3											1	2
Switch	2920 714 6128	1						1							1
Generator	2920 786 1175	10	2		1			3	1			2	1		6.5
Relay Starter	2920 897 6732	1										1			-
Relay	2920 897 6733	3				1		2							1.5
Screen	2930 678 4667	1												1	-
Filter	2940 580 6283	1										1			-
Hose	2940 673 3191	4					1			1	2				1
Gasket	2940 678 3277	1					1								-
Gasket	2940 678 3278	12					1	5		1			1	4	2
Hose	2940 678 4732	2								2					2
	2940 678 4736	1								1					-
Baffle	2940 678 4737	2									2				1
Gasket	2940 699 6281	1												1	-
Impeller	2940 726 8983	1								1					-
Filter	2940 884 0614	1												1	-
Pipe	2990 678 3250	1												1	-
Pipe	2990 678 3251	3					1			1			1		-
Pipe	2990 678 3252	2									2				-
Pipe	2990 678 3264	2									1			1	-
Turbo Charger (LH)	2990 678 4677	2				1		1							7
Turbo Charger (RH)	2990 678 4678	1									1				6

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions												Average Recorded Man Hours
			0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	
Bearing	3110 100 0337	2							1	1					2
Bearing	3110 100 0593	5							2	1			2		2
Bearing	3110 100 0684	10					1		2	3	1		2	1	1.5
Cone	3110 100 3115	1										1			-
Bearing	3110 100 3617	9							2	2	1		2	2	1
Bearing	3110 151 9395	3												3	1.5
Bearing	3120 692 9104	6							1	4	1				-
Bolt	3306 799 7722	1										1			-
Cone	3410 100 3617	1												1	1
Cone	3930 100 0684	1												1	2
Chain	4010 641 1118	1											1		-
Seal	4320 171 6316	1								1					-
	4510 741 2238	1					1								-
Vent	4720 218 1183	2										1	1		-
Hose	4720 837 7121	3						1	1				1		1
Fitting	4730 050 4208	1									1				-
Fitting	4730 278 5660	1												1	-
Fitting	4730 288 7820	1			1										-
Shim	4730 332 0054	1					1								-
Plug	4730 705 8037	2			1	1									-
Coupler	4730 738 8573	1												1	1
Cross	4730 903 7228	1												1	1
Valve	4820 287 6119	1				1									-
	4820 595 3337	1									1				-
	4933 652 9950	1										1			-
Bearing	5120 592 9104	2										1		1	2
Pin	5135 685 1691	1												1	.5
Spring	5240 597 9497	1												1	5
Bolt	5305 018 1364	2								1				1	-
Screw	5305 019 0100	2									2				-
Screw	5305 022 0821	1												1	.5
Screw	5305 022 3808	1									1				-
Screw	5305 057 1273	1										1			.5
Bolt	5305 297 0700	1								1					-
Bolt	5305 501 1313	1								1					-
Bolt	5305 527 4181	3											2	1	-
Screw	5305 550 1313	1					1								-

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions												Average Recorded Man Hours
			0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	
Bolt	5305 559 7357	1											1		-
Screw	5305 551 0348	1		1											-
Screw	5305 576 1429	1												1	-
Screw	5305 576 7428	10						1			8	1			-
Shock	5305 591 9244	1										1			-
Bolt	5305 621 5318	1												1	.5
Screw	5305 638 8902	2						1		1					-
Bolt	5305 699 6300	1					1								-
Screw	5305 726 5596	3		3											-
Screw	5305 737 5694	1												1	.5
Lock	5305 795 3124	1												1	-
Bolt	5306 042 3568	1									1				-
Washer	5310 011 6124	1			1										-
Nut	5310 042 7673	1							1						-
Nut	5310 514 6158	2											2		-
Lock	5310 514 6162	1											1		-
Washer	5310 538 0829	1									1				-
Washer	5310 582 5977	3				1							1	1	1.5
Washer	5310 596 7029	1												1	.5
Gasket	5310 599 9014	1									1				-
Nut	5310 655 9860	1										1			-
Washer	5310 737 4145	1								1					-
Nut	5310 741 4564	1												1	.5
Nut	5310 752 1166	3										1	1	1	-
Nut	5310 772 3309	1										1			-
Washer	5310 799 7748	1							1						-
Pin	5315 058 5936	1											1		.5
Key	5315 187 1811	1												1	-
Pin	5315 501 3424	1						1							-
Pin	5315 620 0399	4								2	2				-
Spring	5315 690 0542	5				1				1	3				-
Pin	5315 699 7761	1								1					-
Contact	5315 741 4201	1										1			-
Pin	5315 768 4609	1												1	-
Pin	5315 769 4609	1												1	-
Pin	5315 769 6909	6									1			5	-
Pin	5315 769 7609	1												1	-
Pin	5315 769 9609	23				1	1	3	6	7	4		1		8

TABLE F3 (continued)

Nomenclature	[illegible]	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Pin	5315 [illegible] 5102	2										1		1	-
Pin	5315 [illegible] 5626	8				3		1	1	2				1	2
Grommet	[illegible] [illegible] 5426	1										1			-
Packing	[illegible] 694 6673	1					1								1
	5330 514 5678	1						1							1
Seal	5330 531 3299	[illegible]				1		1				1	2	2	.5
Seal	5330 531 3799	1												1	-
Seal	5330 542 1970	1												1	1
Seal	5330 551 2053	1					1								2
Seal	5330 557 3299	1										1			1
Gasket	5330 559 9014	1												1	.5
Seal	5330 641 [illegible]	1												1	-
Seal	5330 673 4753	1							1						-
Excluder	5330 678 3161	1									1				10
Seal	5330 678 3322	3								2				1	4
Seal, Arm Assy	5330 678 4753	37				2	8	9	1	5	5	1	1	5	8
Spring	5340 200 6350	2	1	1											16
Spring	5340 200 6352	1												1	.5
Latch	5340 278 4771	1									1				-
Pin	5340 316 0785	2												2	.5
Ring	5340 526 3947	2								2					-
Strap	5340 543 3188	1									1				-
Seal	5340 550 9359	1									1				-
Spring	5340 597 9497	1												1	1
Latch	5340 600 4152	1												1	.5
Bushing	5340 604 2989	2										1		1	-
Latch	5340 678 4771	1									1				-
Strap	5340 682 1499	1									1				-
Bushing	5340 690 7933	1										1			-
Spring	5340 740 1679	1												1	.5
Spring	5340 740 4679	1					1								-
Spring	5340 740 4680	2					1		1						-
Ring	5340 815 5722	1						1							-
Pin	5340 816 0785	2												2	.5
Hinge	5340 821 4494	12					1			2	2	7			-
Knob	5355 507 9010	1												1	.5
Knob	5355 682 6574	1												1	.5

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions												Average Recorded Man Hours
			0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	
Switch	5430 735 4063	1												1	-
Seal	5530 542 1970	1												1	2
	5965 204 6939	1				1									1
Rheostat	5905 302 1143	2								1	1				.5
Circuit Breaker	5925 026 4767	5	1										1	3	.5
Circuit Breaker	5925 036 4767	1									1				.5
Circuit Breaker	5925 561 0677	4	2							1				1	1
Switch	5930 188 7252	1								1					-
Switch	5930 216 5463	2	1											1	-
Switch	5930 296 6318	1									1				-
Headlight	5930 361 8456	1						1							-
Transmitter	5935 692 9254	2							1	1					1
Gage	5930 694 9288	1												1	.5
Switch	5930 699 9083	6						1		3	2				-
Switch	5930 699 9084	6							1	2	3				-
Switch	5930 699 9085	4								1	3				-
Switch	5930 699 9086	13			2	4		1	1	1	1			3	1.5
Switch	5930 732 0651	3								1	1			1	.5
Switch	5930 735 4063	8					2	1		1		1		3	1
Switch	5930 776 6916	2											1	1	-
Switch	5930 796 8845	2		1		1									1
Plug	5935 686 9963	1										1			-
Connector	5935 752 4942	2												2	.5
Connector	5935 752 4943	3								2				1	.5
Connector	5935 833 8561	1							1						-
Relay	5945 333 0457	1									1				-
Relay	5945 476 2585	3				1					2				1
Relay	5945 612 5740	1						1							2
Relay	5945 640 2707	7				3			2	1			1		-
Nut	5975 771 6634	1										1			-
Switch	5930 699 9084	1											1		-
Motor	6105 333 0461	3					2			1					3.5
Motor	6105 801 8716	8						6		1	1				-
Motor	6105 873 5379	15	1							5	5	1	1	2	1.5
Battery	6130 057 2254	10				1		1		2	5			1	2
	6145 705 6674	1								1					1

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Wire	6145 772 0853	1							1						-
	6145-315-3106	1											1		-
	6220 025 3676	1					1								2
Light	6220 026 4759	3		1		1		1							-
Gasket	6220 047 4103	2												2	.5
Lens	6220 279 7425	2								1	1				.5
Lamp	6220 337 8463	4								2	1		1		-
Lens	6220 557 8229	1												1	-
Reflector	6220 694 8105	1												1	-
Lens	6220 699 8104	2					1							1	.5
Reflector	6220 699 8105	1										1			-
Lens	6220 699 8184	1												1	-
Light	6220 741 1847	4								1	3				.5
Housing	6220 741 8470	1									1				-
Lens	6220 752 5994	2							2						-
Door	6220 752 6020	6							2	2				2	-
Bulb	6240 019 0798	1								1					-
Bulb	6240 019 0877	25	1			1	1		1	5	2	5	3	6	.5
Light	6240 019 0882	1									1				-
Lens	6240 019 0887	2							1	1					-
Bulb	6240 019 3092	2								1	1				-
Bulb	6240 019 3093	12			1				2	1	1	7			-
Lamp	6240 019 3102	7						1					6		-
Bulb	6240 019 9940	1										1			-
Lamp	6240 044 6914	9							1		3		3	2	-
Lamp	6240 155 7836	1								1					-
Lamp	6240 155 7929	1								1					-
Lamp	6240 155 8714	3						1	1			1			-
Lamp	6240 266 9940	4								2	1	1			-
Bulb	6240 266 9949	1							1						-
Lamp	6240 295 2668	4		1					1	1				1	-
Light	6240 368 4472	1												1	-
Head Lamp	6240 368 4972	36				2	1	3	3	3	12	1	3	8	-
Gage	6620 795 0330	1										1			-
Gage	6680 514 5494	1												1	-
Shaft, Tach	6680 752 7482	1				1									1
Tachometer	6680 772 7466	3								1	1	1			.5

TABLE F3 (continued)

Nomenclature	FSN	Total Replacement Actions Recorded	Replacement Actions 0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5500-5999	Average Recorded Man Hours
Speedometer	6680 776 0396	9			1				2	4	1	1			-
Gage	6685 333 5005	2									1		1		1
Transmitter	6685 506 1639	5				1					3			1	-
Gage	6685 514 5491	3	1		1					1					1
Gage	6685 514 5492	1			1										-
Cage	6685 514 5493	5	1	2	2										1
Indicator	6685 514 5495	5					2				1		1	1	-
Indicator	6685 514 5995	2												2	1
Cone	5110 100 0684	1												1	-
Seal	9320 171 6316	13			5				1	1	1		2	3	.5
Wire	9505 554 0098	1								1					-
	9903 205 1795	1											1		-
Reflector	9905 205 2795	1									1				-
TOTAL		1463	31	52	29	74	109	146	106	203	266	92	110	245	

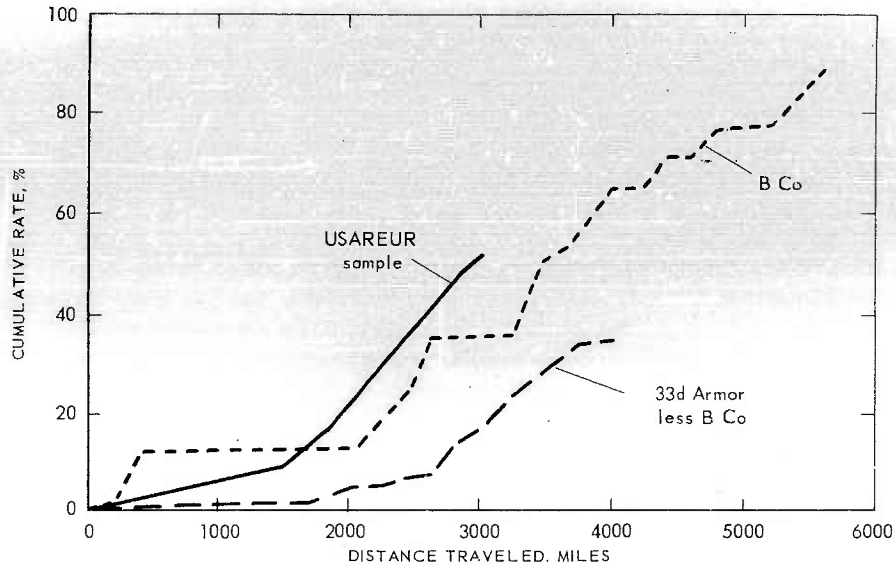


Fig. F7—Rates of Replacement of Engines of M60 Tanks

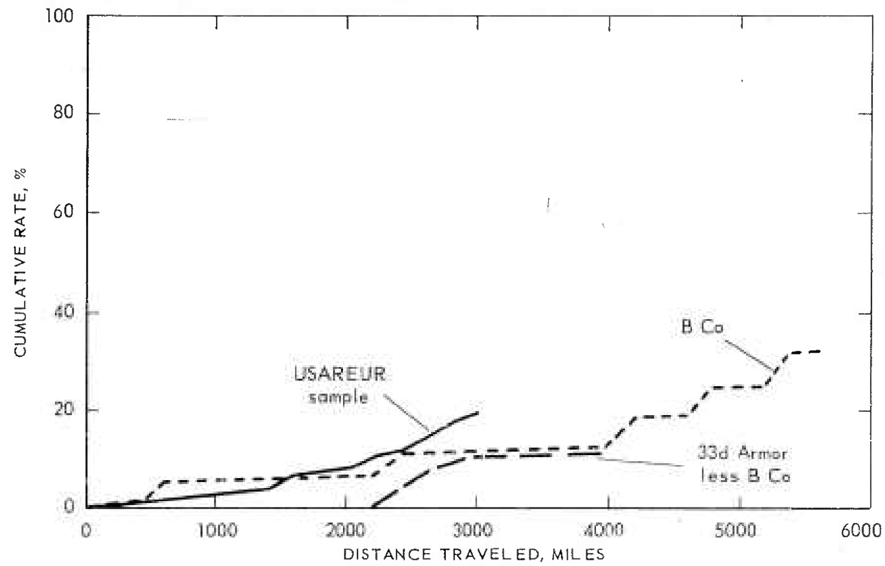


Fig. F8—Rates of Replacement of Transmissions of M60 Tanks the rate developed by the other tanks in the battalion. From the comparison made between the engine replacement rate of the total USAREUR sample of 640 tanks with that of B Co it can be seen that after the early replacements the engines of the company's tanks performed somewhat better than did those of the total sample. The replacement rates related to the total sample are shown on the several charts only up to 3200 miles because the number of tanks having experience beyond this mileage is relatively small. The same comparisons as made above are shown in Fig. F8 for the tank transmissions. From this chart it can be seen that, as was the case with engines, B Co's tank transmissions did not perform as well as those of the remaining tanks in the battalion but did outperform those of the total tank sample. It is also quite obvious from this chart that the replacement rate for transmissions is moderate even out to 6000 miles. From these comparisons it can also be seen that all tanks in the 1st Bn, 33d Armor, performed better than those in the USAREUR sample. This is shown by the change in direction of the replacement-rate curve for the USAREUR sample tanks that occurred during the second 1000 miles and the more pronounced slope of the curve.

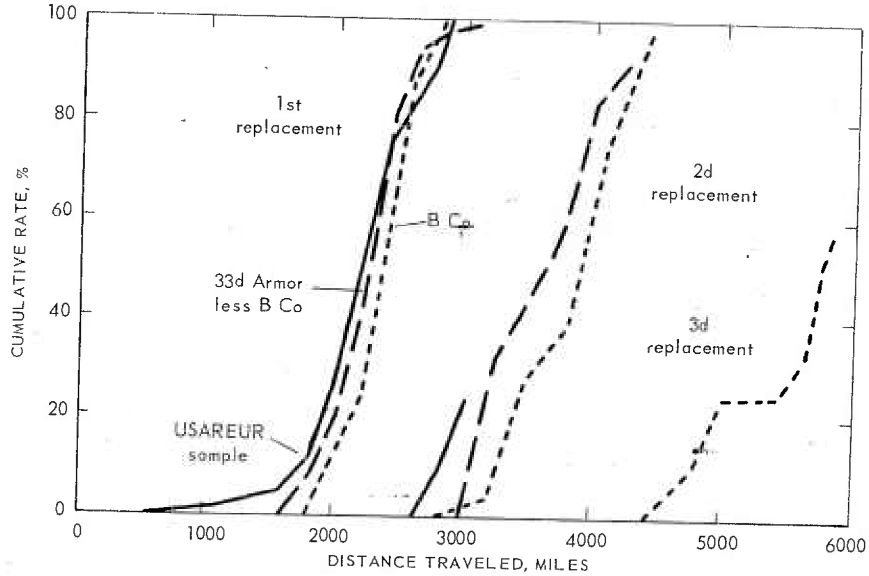


Fig. F9—Rates of Replacement of Track-Shoe Assemblies of M60 Tanks

In Fig. F9 the same comparison is made for track-shoe assemblies. The track-shoe-assembly replacement rates for first, second, and third replacements are shown. The first replacement is the replacement of the original track shoes. This figure shows that all the original track on B Co's tanks was replaced between 1900 and 2800 miles and that the other tanks in the battalion had 100 percent replacement between 1600 and 3200 miles. From this chart it can be seen that although B Co experienced track replacement somewhat later, the rate of replacement was very similar to the replacement rate for the other tanks in the battalion. Based on the data from which the first replacement curves were derived, an average of 2200 miles was calculated as the life of M60 tank track, and this average can be observed by an examination of these curves. It is believed that this track life represents the most accurate figure available, for the track supply situation at that time was such that it could readily meet the demands. It is quite probable that after that time numerous tanks continued to use track beyond the period where inspection justified replacement. This may have occurred because of the general unavailability of tank track and because of the unsatisfactory experience of 1st Bn, 33d Armor, with rebuilt track. The low mileage life of the first replacements can be seen by a comparison of the first and second replacement curves of the company or battalion. It is probable that the first replacement track was a combination of new and rebuilt track. The quality of this rebuilt track can be demonstrated by the decrease in mean track life from 2200 miles to approximately 1400 miles. It also appears that the second replacement was affected by the use of rebuilt track. Although the replacement rate for the USAREUR sample shows that track replacements occurred much earlier the figure indicates that after 1500 miles the rates curves are quite similar. Tank experience beyond 3000 miles was limited for the total sample and beyond 4000 miles for the 1st Bn, 33d Armor, less B Co. This limitation is reflected in the replacement rates in this and following figures.

The replacement rates for two additional suspension-system parts are presented in Figs. F10 and F11. The replacement rate for the final-drive sprockets shown in Fig. 10 is similar to that of the first track replacement but occurs later in the mileage life of the company's tanks and later in the mileage life of the battalion-less-the-company's tanks. A rotation of the sprocket wheels was made at approximately 1400 miles. For the USAREUR sample the sprocket andfirst-track-replacement rates were the same out to 1600 miles. After this mileage, however, the sprocket-replacement rate was less pronounced than that of the track. On the M60 tank the road and idler wheel are identified by the same FSN and the replacement rate developed was based on this rather than on the position the wheel occupied in the suspension system. The replacement rates based on quantity for road and idler wheels is presented in Fig. F11 and shows that this item required only moderate replacement through 3800 miles in the 1st Bn, 33d Armor. After this mileage, however, B Co's curve indicates a marked increase in wheel replacement. The replacement curve of the USAREUR sample is very similar to that of the battalion out to 2500 miles, at which point a more pronounced replacement rate begins to develop. The replacement rates for generators, starters, and fuel-injection pumps are shown in Figs. F12 to F14. For these parts, as for the previous three, B Co's tanks experienced somewhat better performance than did the other tanks in the battalion or the total sample as a whole. No effort has been made to extrapolate the rates pertaining to the battalion less B Co or the USAREUR sample beyond the actual data experience. Although additional replacement-rate comparisons could be presented it is believed that the samples offered above are sufficient to demonstrate the replacement experience of tanks with nearly 6000 miles of usage and to provide some worthwhile comparisons.

From the data collected on part replacements it is possible to differentiate between those made in relation to scheduled maintenance from those performed

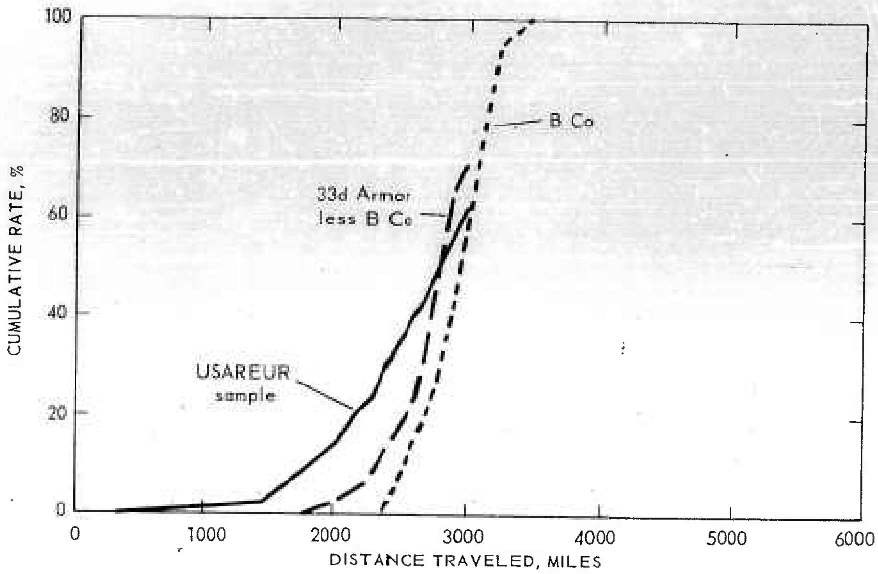


Fig. F10—Rates of Replacement of Final-Drive Sprockets of M60 Tanks

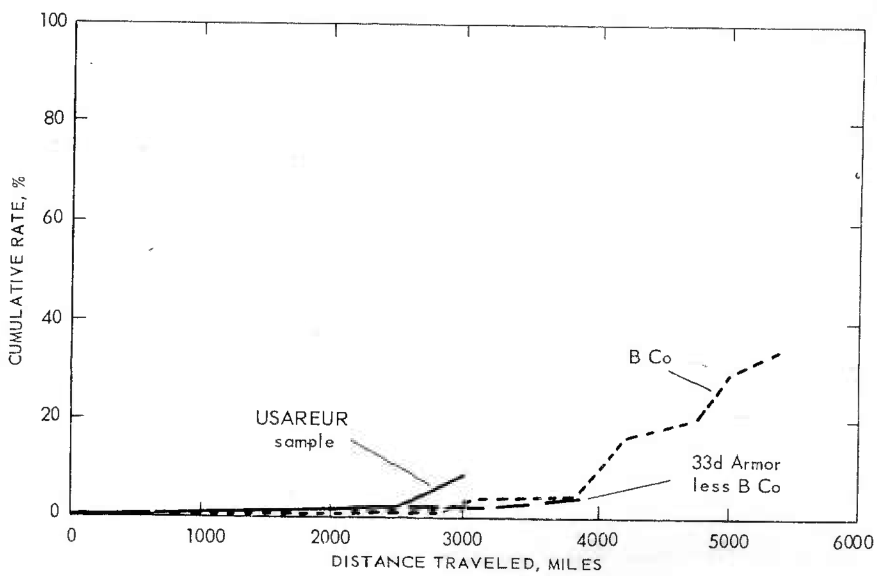


Fig. F11—Rates of Replacement of Road and Idler Wheels of M60 Tanks

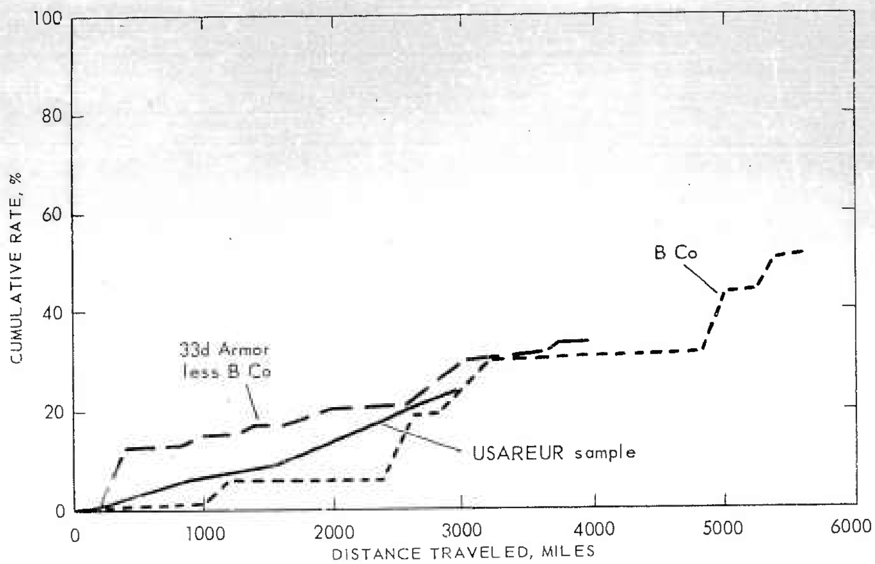


Fig. F12—Rates of Replacement of Generators of M60 Tanks

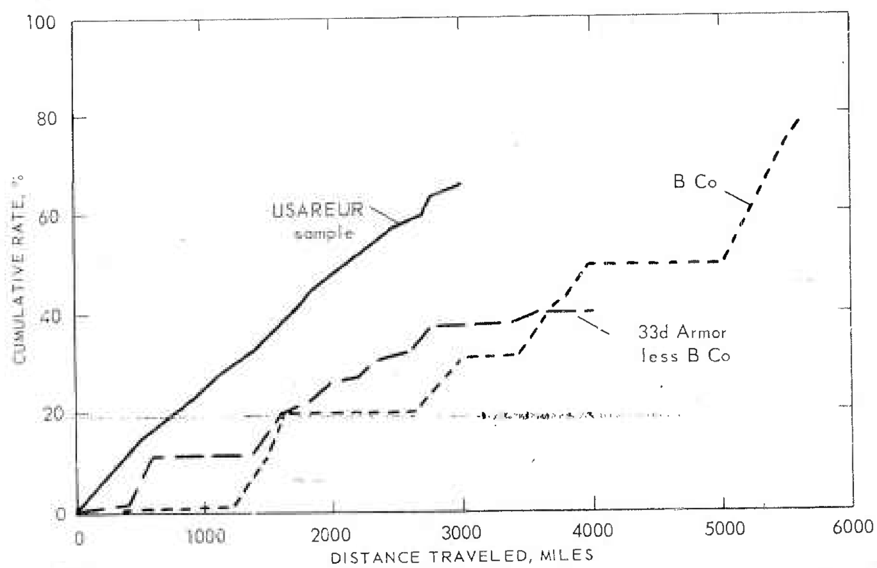


Fig. F13—Rates of Replacement of Starters of M60 Tanks as nonscheduled maintenance. A graphic presentation of an analysis made on the above basis of the replacement data from B Co and from the 1st Bn of the 33d Armor, less B Co is shown in Fig. F15. From this figure it can be seen that a greater percentage of maintenance actions involving the replacement of parts occurred during scheduled maintenance on B Co tanks than on the

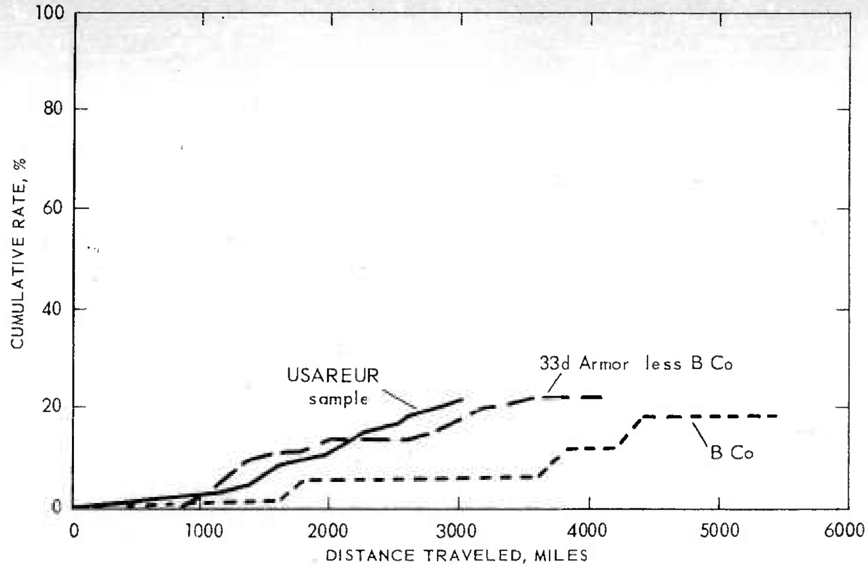
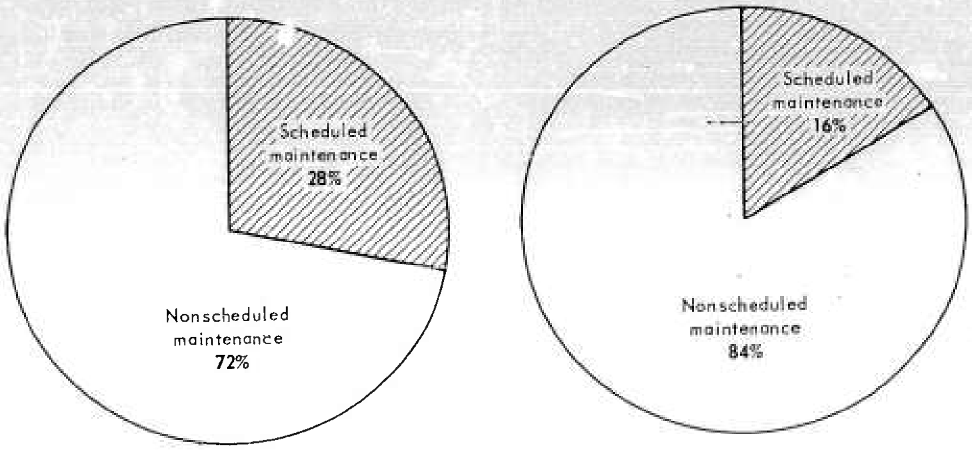


Fig. F14—Rotes of Replocement of Fuel-Injection Pumps of M60 Tanks

battalion less B Co. The total number of replacement actions represented are 1463 for B Co and 2835 for 1st Bn, 33d Armor, less B Co. The percentage of the quantity of parts replaced in the performance of these actions related to scheduled and nonscheduled maintenance is shown in Fig. F16.

Adjustment, Repair, and Replacement

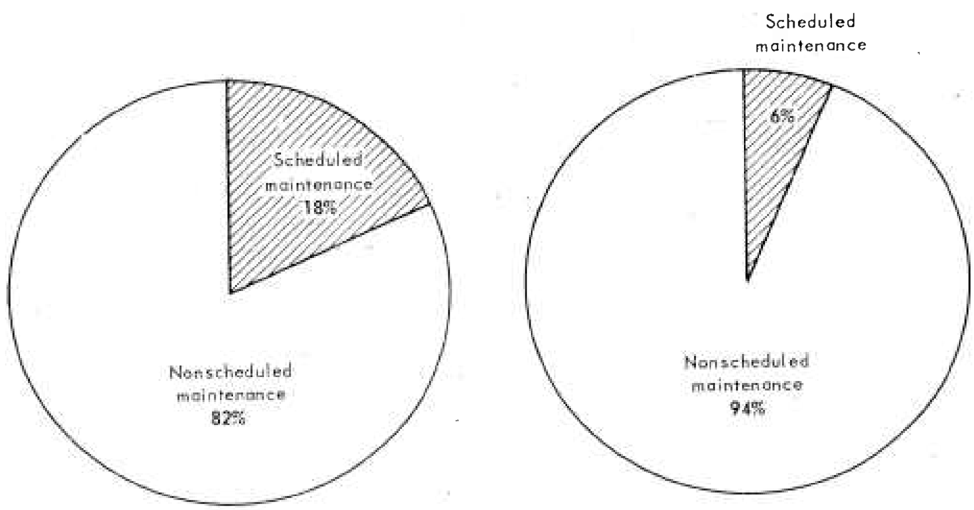
Based on a broad and thorough review of equipment logbooks it appears that more emphasis is placed on the recording of information pertaining to parts replacement than to the adjustment and repair type of maintenance performed. The ~~latter~~ actions, however, are of no small consequence in relation to time, labor, tank performance, and money. As mentioned previously, the data bank for the "depth units," 1st Bn, 33d Armor, and the 2d Bn, 37 Armor, contains all recorded maintenance actions. An examination of these data shows that only about 25 percent of the total recorded maintenance actions pertain to adjustment- and -repair-type maintenance. Only a limited analysis has been made of this type of data. For several of the analyses, adjustment and repair actions have been combined because of the almost one-to-one ratio of adjustments to repairs (230 adjustments and 253 repairs) and because of the limited quantity of this type of data.



a. B Co

b. 1st Bn, 33d Armor less B Co

Fig. F15—Parts Replacement Actions in Scheduled and Nonscheduled Maintenance of M60 Tanks



a. B Co

b. 1st Bn, 33d Armor less B Co

Fig. F16—Percentage of Parts Replaced in Scheduled and Nonscheduled Maintenance of M60 Tanks

All adjustment, repair, and replacement activities recorded in B Co are shown cumulatively distributed over 6000 miles of tank usage in Fig. F17. Both the combined adjustment and repair curve and the replacement curve show an increase in activity after 2000 miles with the rate of increase more

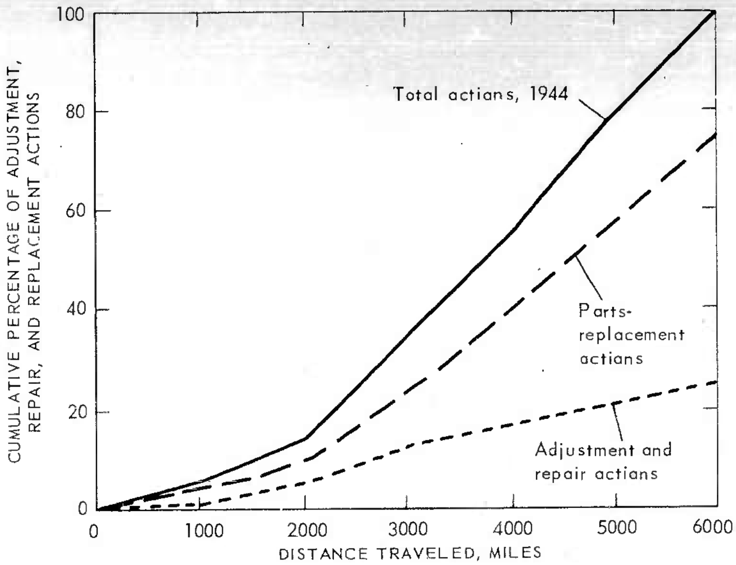


Fig. F17—Recorded Adjustment, Repair, and Replacement Actions for M60 Tanks of B Co, 1st Bn, 33d Armor

pronounced in the replacement curve. After 3000 miles both curves show a change in direction indicating a change in the rate of activity. Although the rate of change in relation to total activity for adjustment and repair actions appears to be increasing at a lower rate after the third 1000-mile interval, the limited observation between these two mileage points must be kept in mind. When the adjustment and repair actions are combined the derived curve shows the rate of increase indicated in Fig. F17. From the distribution shown in Fig. F18 the variations that occur in the adjustment and repair activity for the several mileage intervals are quite obvious. These variations must be kept in mind when considering the combined cumulative curve shown in Fig. F17. It should be noted that these charts are based on recorded activity only and although these recorded activities are incomplete they do provide some indication of the scope of nonreplacement maintenance activity and are therefore included to present as broad a view as possible of the maintenance performed.

Figures F19 and F20 show the average number of recorded adjustment and repair maintenance activities per tank for the 1st Bn, 33d Armor less B Co, and the 2d Bn, 37th Armor, respectively. In the battalion less the company the combined adjustment and repair activity was approximately 25 percent of the

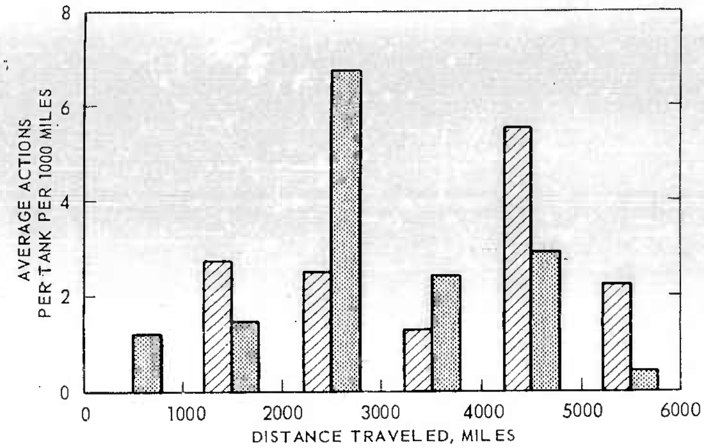


Fig. F18—Average Recorded Adjustment and Repair Actions per M60 Tank of B Co

Adjustments Repairs

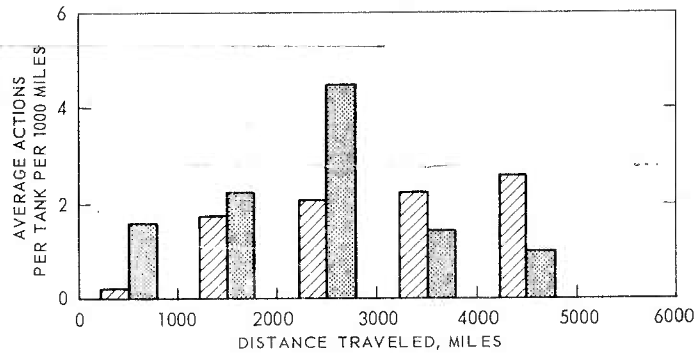


Fig. F19—Average Recorded Adjustment and Repair Actions per M60 Tank of 1st Bn, 33d Armor less B Co

Adjustments Repairs

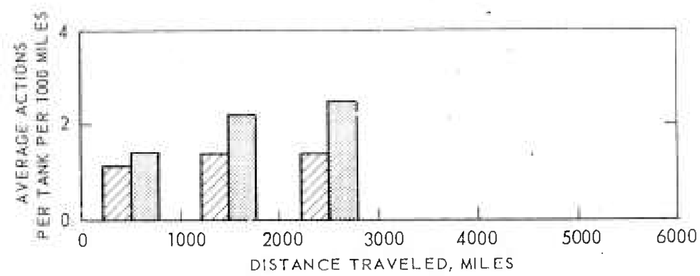


Fig. F20—Average Recorded Adjustment and Repair Actions per M60 Tank of 2d Bn, 37th Armor

Adjustments Repairs

total maintenance data collected. In the 2d Bn, 37th Armor, it was about 20 percent of the total maintenance data collected. By comparing Figs. F18 to F20 it can be seen that the data showed no well-defined trends and that wide variations occurred between the two battalions. A comparison is made in Fig. F21 of the average number of all adjustment, repair, and replacement activities performed per tank by B Co and by the battalion less B Co. The percentage of the total actions performed by second- and third-echelon maintenance as distributed over the various mileage intervals is shown for B Co; 1st Bn, 33d Armor, less B Co; and the 2d Bn, 37th Armor, in Figs. F22, F23, and F24 respectively. From these charts it is quite obvious that the largest proportion of the maintenance activities were performed at the second echelon. Of the total actions, less than 15 percent were performed at the third echelon. As may be noted from the figures the maintenance load at this echelon was relatively constant.

In Fig. F25 the data pertaining to adjustment and repair activity, like that of parts replacements, are identified in relation to scheduled and nonscheduled maintenance. From this chart it can be seen that 62 percent of the combined adjustment and repair actions recorded by B Co were related to scheduled maintenance. This figure is 40 percent greater than that of the battalion less B Co. The result of combining the former activities with the replacement activity on this basis is shown in Fig. F26. This figure shows that 37 percent of all maintenance actions recorded by B Co were related to scheduled maintenance and that 21 percent of the total was replacement activity. For comparative purposes the chart includes the results of the same analysis made of the data from the battalion less B Co. These charts provide some indication of the importance of scheduled maintenance in the operation of B Co's tanks.

Direct Labor Man-Hours

Direct labor man-hours are those used in performing tank maintenance involving either adjustment, repair, replacement, or inspection actions. These types of data were collected to the greatest extent possible, but only a limited quantity was available. In the 1st Bn of the 33d Armor, only 35 percent of all adjustment, repair, and replacement data collected contained the number of man-hours used to perform the maintenance action. For B Co only 37 percent of the data collected showed man-hours. Because of the paucity of recorded data on this subject no conclusions could be drawn.

The analysis has been restricted to the adjustment, repair, and replacement actions. When these actions were performed during an inspection and only the total number of hours required for the inspection was recorded, no effort was made to allocate the time to the separate actions performed.

Tables F4 to F6 show the number of maintenance actions recorded and the number of actions for which man-hours were recorded, segregated by maintenance echelon and distributed by 500-mile increments, for B Co and the 1st Bn of 33d Armor, less B Co. Based on the actual number of man-hours recorded, the average number of man-hours per tank per 500 miles for the combined adjustment, repair, and replacement actions is shown in Fig. F27 for B Co and 1st Bn of 33d Armor, less B Co. The marked increase in the average number of man-hours per tank in the intervals between 1500 and 3000 miles again reflects maintenance activity related to the tank's suspension

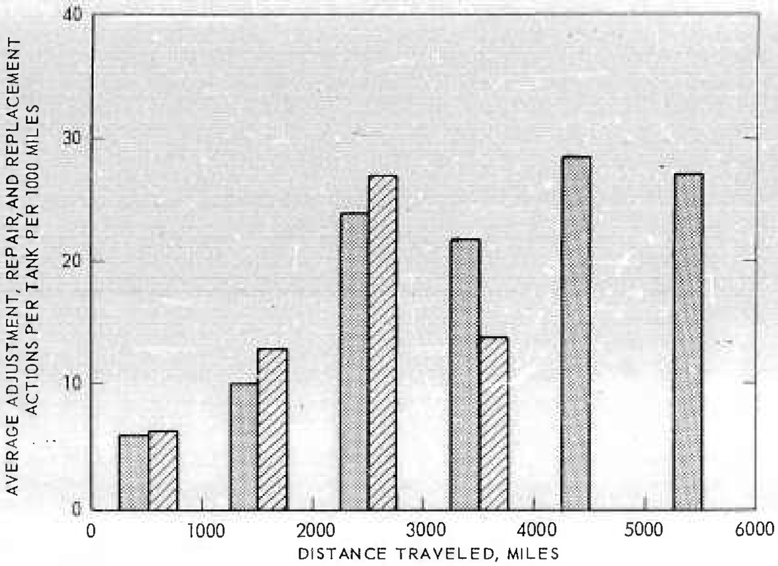


Fig. F21—Comparison of the Average Adjustment, Repair, and Replacement Actions Recorded per M60 Tank by B Co and 1st Bn, 33d Armor, less B Co

B Co 1st Bn, 33d Armor, less B Co

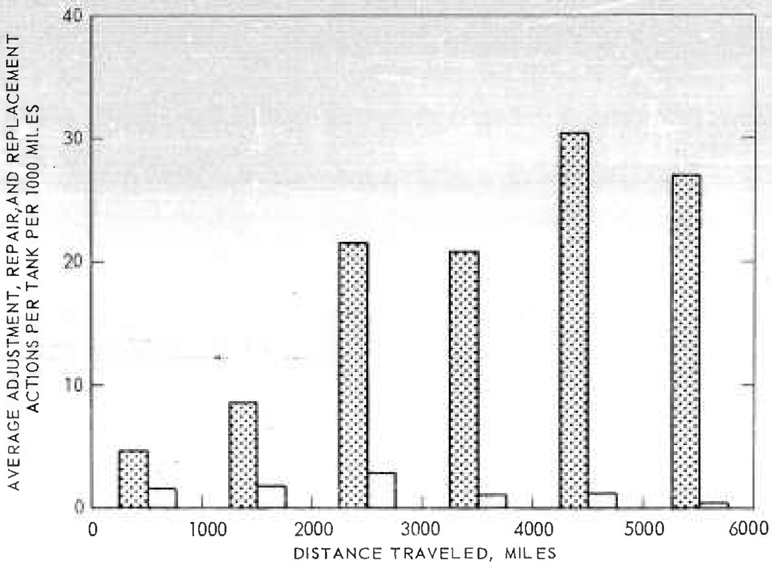


Fig. F22—Average Recorded Adjustment, Repair, and Replacement Actions per M60 Tank Performed by Second- and Third-Echelon Maintenance for B Co

Second Echelon Third Echelon

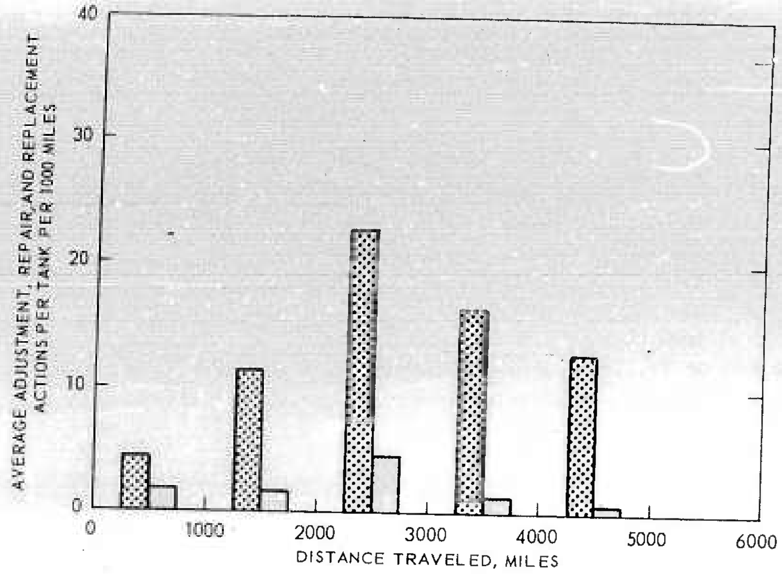


Fig. F23—Average Adjustment, Repair, and Replacement Actions per M60 Tank Performed by Second- and Third-Echelon Maintenance for 1st Bn, 33d Armor, less B Co

Second Echelon Third Echelon

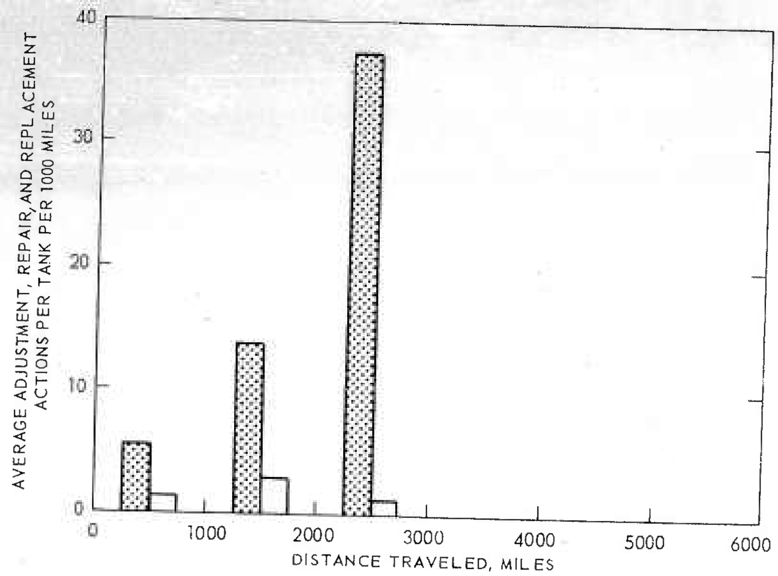
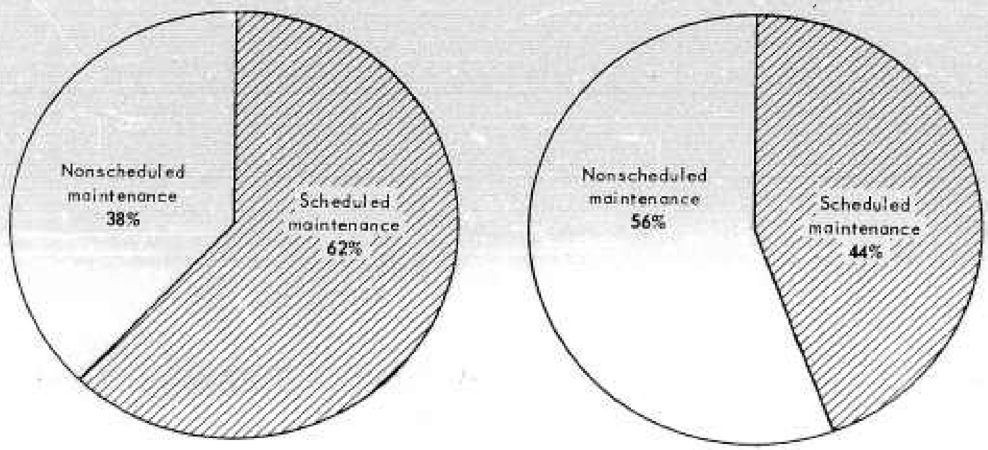


Fig. F24—Average Adjustment, Repair, and Replacement Actions per M60 Tank Performed by Second- and Third-Echelon Maintenance for 2d Bn, 37th Armor

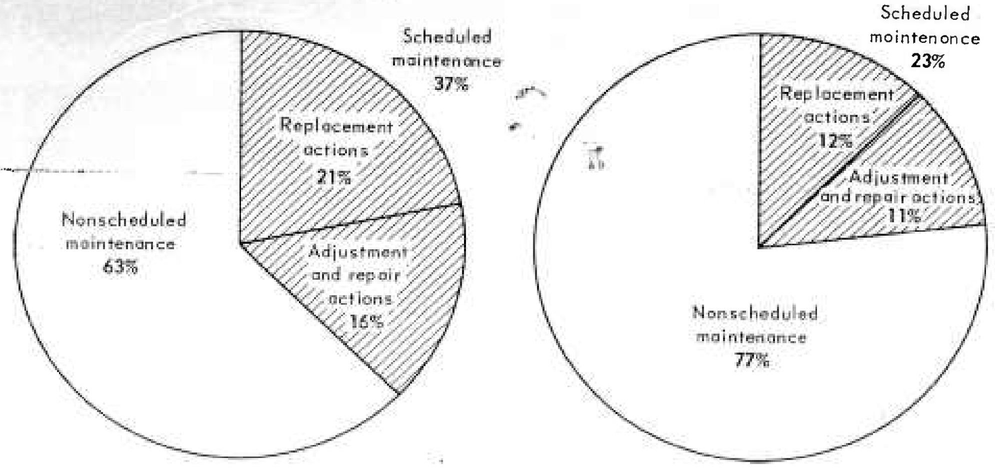
Second Echelon Third Echelon



a. B Co

b. 1st Bn, 33d Armor, less B Co

Fig. F25—Percentage of Adjustment and Repair Actions in Scheduled and Nonscheduled Maintenance of the M60 Tank



a. B Co

b. 1st Bn, 33d Armor, less B Co

Fig. F26—Percentage of Adjustment, Repair, and Replacement Actions in Scheduled and Nonscheduled Maintenance of the M60 Tank

TABLE F4

Recorded Maintenance Actions and Labor Man-Hour Distribution by 500-Mile Increments for the M60 Tank[a]

Action category	Mileage increments												Total actions	Total actions with man-hours	Total man-hours recorded	Percent of actions with man-hours recorded
	0-499	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500				
B Co, Second Echelon																
Recorded replacements																
Actions only	18	49	27	57	94	138	100	198	259	82	107	245	1374	—	—	—
Actions with man-hours	9	33	8	27	31	67	22	48	56	25	25	113	—	464	—	34
Total, man-hours	29	52	30	59	215	499	84	190	223	71	38	141	—	—	1631	—
Recorded adjustments																
Actions only	—	—	—	42	20	21	8	12	59	24	22	12	220	—	—	—
Actions with man-hours	—	—	—	29	12	10	1	1	3	6	2	1	—	65	—	30
Total, man-hours	—	—	—	59	11	12	1	1	2	5	5	4	—	—	100	—
Recorded repairs																
Actions only	6	—	2	17	39	53	29	8	36	9	5	1	205	—	—	—
Actions with man-hours	2	—	—	10	15	11	18	—	4	2	—	—	—	62	—	30
Total, man-hours	4	—	—	23	37	41	20	—	11	2	—	—	—	—	138	—
Total recorded actions and time																
Actions only	24	49	29	116	153	212	137	218	354	115	134	258	1799	—	—	—
Actions with man-hours	11	33	8	66	58	88	41	49	63	33	27	114	—	591	—	32
Total, man-hours	33	52	30	141	263	552	105	191	236	78	43	145	—	—	1869	—
B Co, Third Echelon																
Recorded replacements																
Actions only	13	3	2	17	15	8	6	5	7	10	3	—	89	—	—	—
Actions with man-hours	5	2	1	14	14	5	5	4	6	4	3	—	—	63	—	71
Total, man-hours	45	26	2	29	75	44	78	24	64	31	35	—	—	—	453	—
Recorded adjustments																
Actions only	—	—	1	3	—	1	—	2	3	—	—	—	10	—	—	—
Actions with man-hours	—	—	1	3	—	1	—	2	3	—	—	—	—	10	—	100
Total, man-hours	—	—	1	5	—	2	—	3	3	—	—	—	—	—	14	—

TABLE F4 (continued)

Action category	Mileage increments												Total actions	Total actions with man-hours	Total man-hours recorded	Percent of actions with man-hours recorded
	0-499	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500				
Recorded repairs																
Actions only	6	8	1	6	12	10	2	1	—	—	—	—	46	—	—	—
Actions with man-hours	1	8	—	5	11	9	2	1	—	—	—	—	—	37	—	80
Total, man-hours	1	21	—	15	35	20	12	1	—	—	—	—	—	—	105	—
Total recorded actions and time																
Actions only	19	11	4	26	27	19	8	8	10	10	3	—	145	—	—	—
Actions with man-hours	6	10	2	22	25	15	7	7	9	4	3	—	—	110	—	76
Total, man-hours	46	47	3	49	110	66	90	28	67	31	35	—	—	—	572	—
1st Bn, 33d Armor, Less B Co, Second Echelon																
Recorded replacements																
Actions only	53	143	158	296	606	403	208	510	214	9	—	—	2600	—	—	—
Actions with man-hours	24	29	40	108	177	122	11	39	8	—	—	—	—	558	—	21
Total, man-hours	28	27	68	419	1245	871	15	84	21	—	—	—	—	—	2778	—
Recorded adjustments																
Actions only	—	3	14	69	61	51	12	108	59	4	—	—	381	—	—	—
Actions with man-hours	—	2	3	61	44	11	4	84	45	4	—	—	—	258	—	68
Total, man-hours	—	4	4	167	105	179	1	35	9	1	—	—	—	—	505	—
Recorded repairs																
Actions only	12	29	17	72	65	49	34	22	20	1	—	—	321	—	—	—
Actions with man-hours	9	26	8	56	33	16	3	5	3	—	—	—	—	159	—	50
Total, man-hours	17	38	10	147	152	161	7	3	10	—	—	—	—	—	545	—
Total recorded actions and time																
Actions only	65	175	189	437	732	503	254	640	293	14	—	—	3302	—	—	—
Actions with man-hours	33	57	51	225	254	149	18	128	56	4	—	—	—	975	—	30
Total, man-hours	45	69	82	733	1502	1211	23	122	40	1	—	—	—	—	3828	—

1st Bn, 33d Armor, Less B Co, Third Echelon																
Recorded replacements																
Actions only	31	19	23	32	49	43	18	15	5	—	—	—	235	—	—	—
Actions with man-hours	12	8	18	21	29	31	16	7	3	—	—	—	—	145	—	62
Total, man-hours	39	20	70	152	196	206	149	83	45	—	—	—	—	—	960	—
Recorded adjustments																
Actions only	1	5	3	7	4	2	2	4	—	—	—	—	28	—	—	—
Actions with man-hours	—	3	2	4	4	1	2	4	—	—	—	—	—	20	—	71
Total, man-hours	—	5	2	2	8	1	3	4	—	—	—	—	—	—	25	—
Recorded repairs																
Actions only	22	26	12	24	87	48	9	13	2	—	—	—	243	—	—	—
Actions with man-hours	12	14	8	20	82	46	8	9	2	—	—	—	—	201	—	83
Total, man-hours	63	64	18	156	120	77	13	10	3	—	—	—	—	—	524	—
Total recorded actions and time																
Actions only	54	50	38	63	140	93	29	32	7	—	—	—	506	—	—	—
Actions with man-hours	24	25	28	45	115	78	26	20	5	—	—	—	—	366	—	72
Total man-hours	102	89	90	310	324	284	165	97	48	—	—	—	—	—	1509	—
Total for B Co																
Maintenance actions recorded	43	60	33	142	180	231	145	226	364	125	137	258	1944	—	—	—
Actions with man-hours recorded	27	43	10	88	83	103	48	56	72	37	30	114	—	711	—	37
Man-hours recorded	79	99	33	190	373	618	195	219	303	109	78	145	—	—	2441	—
Tanks observed through mileage increment	17	17	17	17	17	17	17	17	17	16	15	14	—	—	—	—
Total for 1st Bn, 33d Armor, Less B Co																
Maintenance actions recorded	119	225	227	500	872	596	283	672	300	14	—	—	3808	—	—	—
Actions with man-hours recorded	57	82	79	270	369	227	44	148	61	4	—	—	—	1341	—	35
Man-hours recorded	147	158	172	1043	1826	1495	188	219	88	1	—	—	—	—	5337	—
Tanks observed through mileage increment	55	55	55	55	55	55	55	54	24	1	—	—	—	—	—	—

[a]Figures do not include the number of man-hours used for MWOs or technical inspections such as are made of track shoes. Further, no allocation was made of scheduled maintenance man-hours not related in the records to specific action performed. Distribution of scheduled preventive-maintenance man-hours shown on Table F6.

TABLE F5

Distribution of Labor Man-Hour Extrapolation[a] by 500-Mile Increments for the M60 Tank

Extrapolation category	Mileage Increments												Total actions	Total extrapolated man-hours
	0-499	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500		
B Co														
Extrapolated man-hours														
Second echelon, repair, adjustment, and replacement actions	72	77	108	248	694	1330	351	850	1326	272	228	328	1799	5,884
Third echelon, repair, adjustment, and replacement actions	146	52	6	58	119	84	103	32	74	78	35	—	145	787
Total	218	129	114	306	813	1414	454	882	1400	350	263	328	1944	6,671
Extrapolated man-hours														
Replacement actions, second echelon	58	77	101	125	652	1028	382	784	1031	233	163	306	1374	4,940
Replacement actions, third echelon	117	39	4	35	80	70	94	30	75	78	35	—	89	657
1st Bn, 33d Armor, Less B Co														
Extrapolated man-hours														
Second echelon, repair, adjustment, and replacement actions	89	212	304	1424	4329	4088	325	610	209	—	—	—	3302	11,590
Third echelon, repair, adjustment, and replacement actions	230	178	122	434	394	339	184	155	67	—	—	—	506	2,103
Total	319	390	426	1858	4723	4427	509	765	276	—	—	—	3808	13,693
Extrapolated man-hours														
Replacement actions, second echelon	62	133	269	1148	4263	2877	284	510	562	—	—	—	2600	10,108
Replacement actions, third echelon	101	48	89	232	331	286	168	178	60	—	—	—	235	1,493

[a]Based on the assumption that labor man-hours not recorded would be distributed approximately the same as those recorded the extrapolation was made from the ratio: the number of actions with man-hours recorded is to the total number of actions as the record man-hours is to the unknown total man-hours, i.e., Action with man-hours/total actions = recorded man-hours/x.

TABLE F6

Recorded Scheduled Preventive Maintenance Actions and Labor Man-Hours Distributed by 500-Mile Increments for the M60 Tank

QM category	Mileage increments											
	0–499	500–999	1000–1499	1500–1999	2000–2499	2500–2999	3000–3499	3500–3999	4000–4499	4500–4999	5000–5499	5500–5999
B Co												
QMs recorded	—	—	2	17	16	23	10	15	32	10	7	—
QMs with man-hours recorded	—	—	2	15	15	22	10	15	32	9	7	—
Man-hours recorded	—	—	14	128	316	793	711	806	2163	560	436	—
1st Bn, 33d Armor, Less B Co												
QMs recorded	—	4	15	48	48	54	19	33	14	1	—	—
QMs with man-hours recorded	—	1	9	44	46	52	16	29	13	1	—	—
Man-hours recorded	—	40	151	1246	1492	2886	955	1957	823	48	—	—

system. The drop in maintenance man-hours for the battalion less B Co after 3000 miles may be due in part to the overhaul program that was being put into effect at that time.

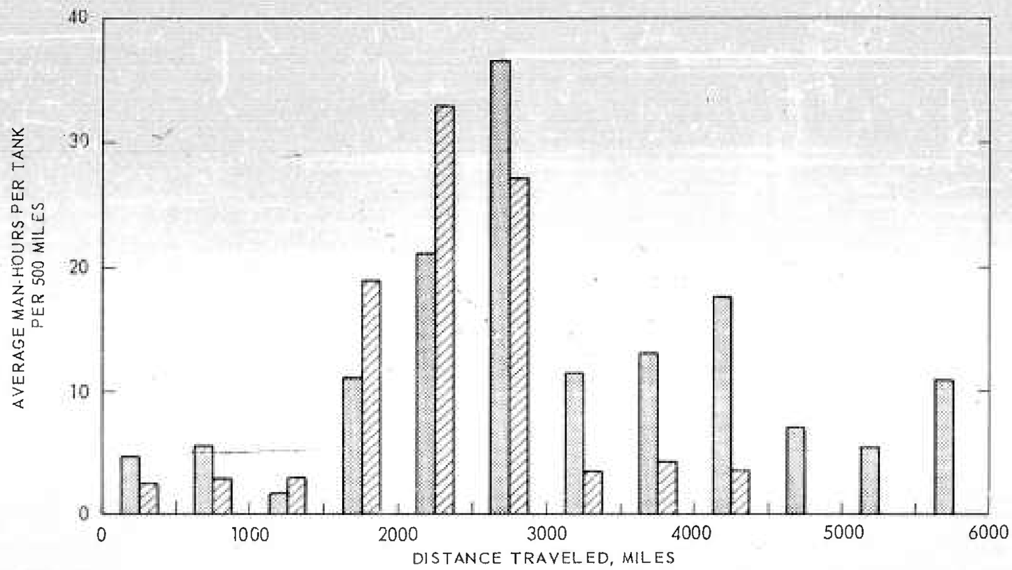


Fig. F27—Average Maintenance Man-Hours for Adjustment, Repair, and Replacement Actions per M60 Tank of B Co and 1st Bn, 33d Armor, less B Co

Actual recorded man-hours—Of all recorded maintenance activity collected, only about 35 percent contained the number of man-hours used in the maintenance performed.

B Co   1st Bn, 33d Armor, less B Co

Parts-Replacement Cost

Through a careful search of price list manuals and Seventh Army stockage lists[8-12] an effort was made to assign a cost figure to all parts-replacement cards. The parts for which a price was not obtained represent less than 1 percent of the total cost figures developed. Engines and transmissions were priced at 30 percent of list price. All other parts were charged at full list price, as no rebuild-cost figures for direct-exchange items have been developed. The replaced parts identified by FSNs were shown in Table F3, which shows the number of replacement actions made of each FSN distributed by 500-mile increments. The number of man-hours (either the average where several parts were replaced and man-hours were recorded or the man-hours recorded when a single replacement was made) are also included. These data are based on the recorded information and although several of the part numbers appear to be drawing numbers, they were included and counted as FSNs.

The total cost of parts replaced on B Co's 17 M60 tanks during 37 months of operation was $415,500. The average cost per tank for this period was $24,400. The average parts cost per month for the company was $10,700. Three items—engines, transmissions, and track-shoe assemblies—accounted for approximately 79 percent of the total parts-replacement cost. Forty-six percent or $192,000 of the total cost was spent on track-show replacement; 30 percent or $123,500 for engine replacement; and 3 percent or $13,900 for transmissions. The cost of the latter two parts represents 30 percent of list price.

The cumulative percentage of the total parts-replacement cost distributed over 6000 miles by 500-mile intervals is shown in Fig. F28. The sharp increase in the rate that occurs between 2000 and 2500 miles reflects the cost of track replacement combined with the cost of three engine replacements. From this chart it can be seen that after 2000 miles of utilization B Co's tanks experienced a marked increase in parts-replacement cost. In Fig. F29 a graphic representation is made of the average parts cost per tank by 1000-mile intervals. For comparative purposes the average costs per tank of B Co, 1st Bn, 33d Armor, less B Co and the 2d Bn, 37th Armor, are presented. The relatively high average cost occurring in the first 1000-mile interval for both B Co and the 2d Bn, 37th Armor, reflects the replacement of several engines. The marked increase that occurs between 2000 and 3000 miles in all units is the result of truck replacement. The peaking of the curves of B Co between 3000 and 4000 and again between 5000 and 6000 miles is also the result of suspension-system-part replacements. The sharp decline in the average cost of the tanks of the battalion less B Co between 4000 and 5000 miles is the result of the anticipated withdrawal of the tanks and the reduction in the number of tanks that did occur at that mileage.

In Figs. F30 to F32 the average cost per mile per tank by 1000-mile increments is shown for engines, transmissions, track, and the total of all other parts. A comparison is made in each figure between the average cost per mile for B Co and for the total USAREUR tank sample. When the cost figures in these bar charts pertaining to B Co are related to the cumulative cost curve shown in Fig. F28, the effect of engine and track-shoe replacement on the shape of the curve is apparent. The variation in the average cost per mile in the different 1000-mile increments is obvious from these charts.

In Table F7 the average cost per mile per tank for the total miles observed is shown for B Co, 1st Bn, 33d Armor, and the total USAREUR tank sample. In developing these figures the cost of replacing track shoes has been amortized over 2200 miles. The amount contributed to the total cost by engines, transmissions, and other parts is also shown.

B CO ROAD MARCHES—HYPOTHETICAL AND ACTUAL

In Vol I of this technical memorandum the concept of a hypothetical 50-mile road march was introduced. A road march of 50-mile duration was selected because from the observations made by RAC personnel of several road marches with different models of tanks, it was found that any impairments within the first 100 miles were most likely to occur in the first 50 miles. The objective of the hypothetical march was to derive a measure of probable mission completion without impairment because of replacement of the prime mobility

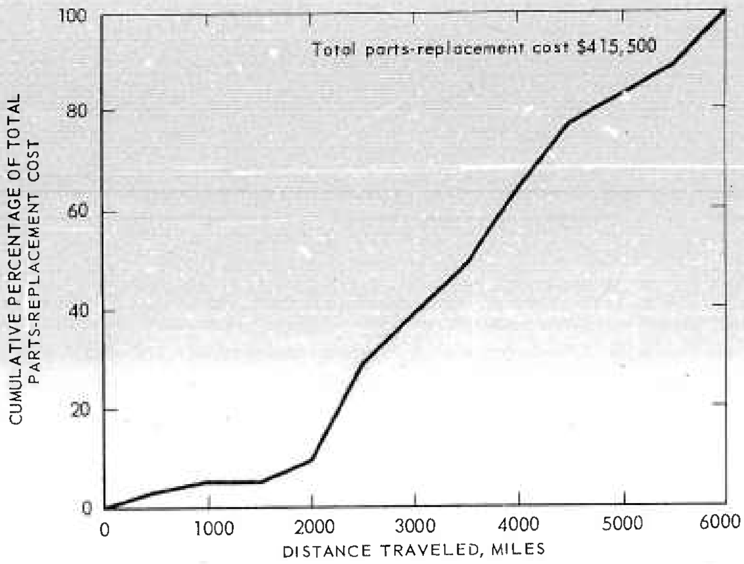


Fig. F28—Cumulative Percentage of Parts-Replacement Cost for M60 Tanks of B Co, 1st Bn, 33d Armor

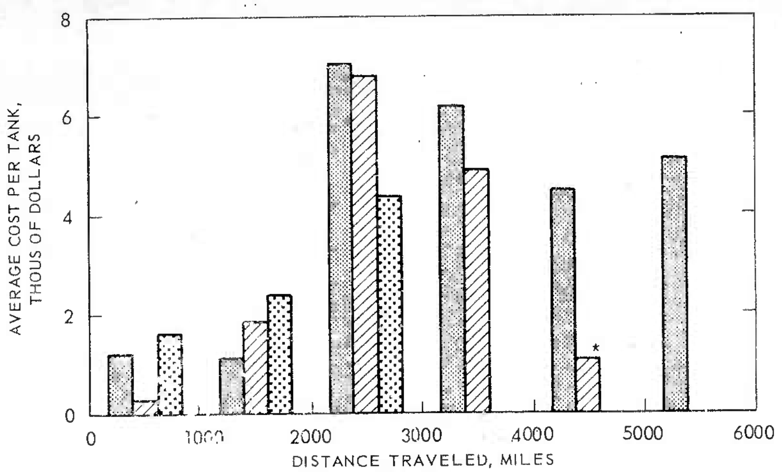
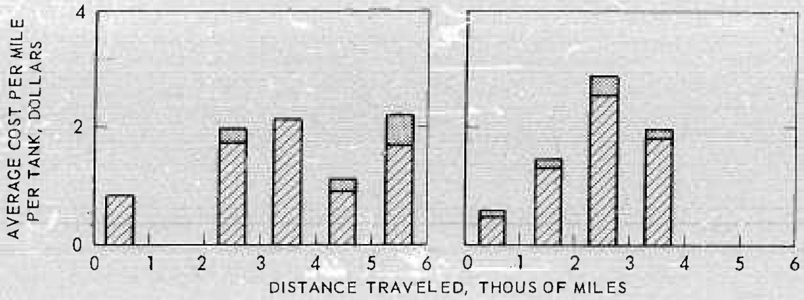


Fig. F29—Average Cost per M60 Tank for Replaced Parts by 1000-Mile Increments in B Co; 1st Bn. 33d Armor, less B Co; and 2d Bn, 37th Armor

*500-mile base

B Co | 1st Bn, 33d Armor, less B Co | 2d Bn, 37th Armor

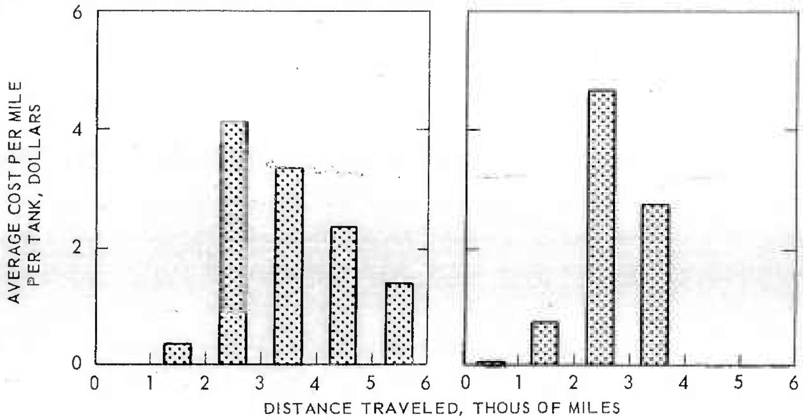


a. B Co, 1st Bn, 33d Armor b. USAREUR Sample

Fig. F30—Comparison of Average Cost of Major Assemblies per Mile per M60 Tank of B Co, 1st Bn, 33d Armor, Compared with USAREUR Sample

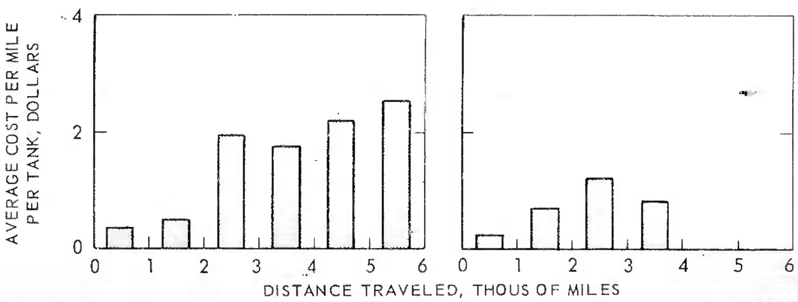
Engines and transmissions at 30 percent of list.

Engine Transmission



a. B Co, 1st Bn, 33d Armor b. USAREUR Sample

Fig. F31—Comparison of Average Cost of Track Shoes per Mile per M60 Tank of B Co, 1st Bn, 33d Armor, Compared with USAREUR Sample



a. B Co, 1st Bn, 33d Armor b. USAREUR Sample

Fig. F32—Comparison of Average Cost of Other Parts per Mile per M60 Tank of B Co, 1st Bn, 33d Armor, Compared with USAREUR Sample

TABLE F7

Average Cost of Parts per Mile per Tank over the Total Number of Miles of Operation Observed

Parts	Cost, dollars/ mile/tank	Cost, dollars/ month/tank
B Co (162 Average Mile/Month; Average 5700 Miles/Tank)		
Engines[a]	1.28	207.36
Transmissions[a]	0.14	22.68
Other parts	0.89	144.18
Track (amortized 2200 miles)	2.05	332.10
Total	4.36	706.32
1st Bn, 33d Armor (161 Average Mile/Month; Average 3850 Miles/Tank)		
Engines[a]	0.84	135.24
Transmissions	0.11	17.71
Other parts	0.68	109.48
Track (amortized 2200 miles)	2.05	330.05
Total	3.68	592.48
USAREUR Tank Sample (130 Average Mile/Month; Average 2750 Miles/Tank)		
Engines[a]	1.19	154.70
Transmissions[a]	0.19	24.70
Other parts	0.32	41.60
Track (amortized 2200 miles)	2.05	266.50
Total	3.75	487.50

[a]At 30 percent of list price.

TABLE F8

Prime Mobility Parts and Assemblies, M60 Tank

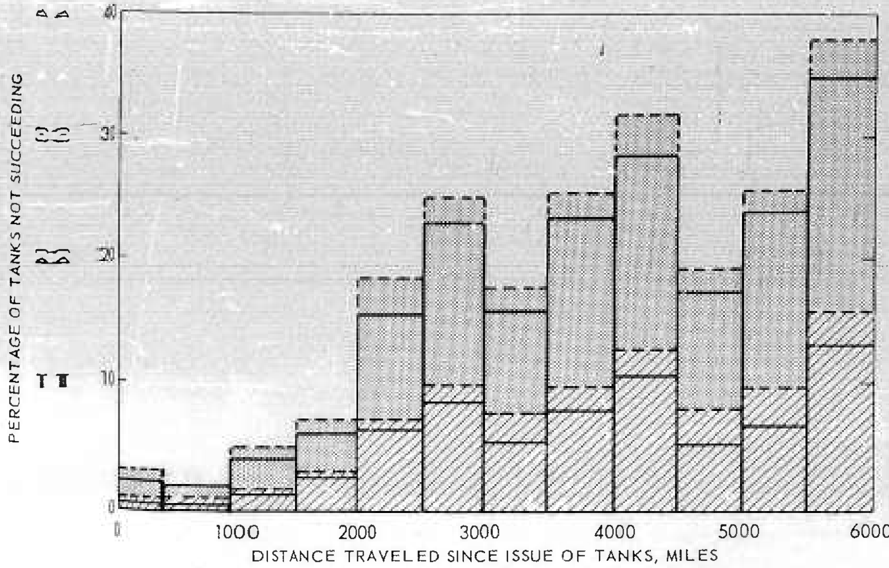
Power train	Sprocket hub
Engine (diesel)	Support roller wheel
Final drive (left and right)	Track shoe assembly
Oil cooler radiator (engine and transmission)	Track tension adjusting link assembly
Transmission	Electrical system
Transmission valve assembly	Battery
Turbo supercharger assembly (LH and RH)	Engine generator
Suspension system	Engine generator regulator
Compensating idler wheel arm assembly	Master relay
Compensating idler wheel hub	Starter
Final drive sprocket	Starter relay
Road and idler wheel	Fuel system
Road wheel hub	Fuel injection nozzle and holder
Road wheel arm assembly	Fuel tank discharge pump
	Metering fuel injection pump

parts shown in Table F8 (see also App D).. The method developed to accomplish this objective was applied to the pertinent data collected from B Co's tanks. In the calculations these data were related to the actual average utilization rate of B Co's tanks (162 miles per month) and to the average utilization rate observed for the total tank sample (130 miles per month). The results of these calculations are shown graphically in Fig. F33, where a comparison is made between B Co and the total USAREUR sample. This figure shows the percentage of tanks that are not expected to complete the 50-mile road march in relation to their miles of operation since issue. The shaded areas on the charts show the predicted percentages of tanks expected to be unable to leave the tank park because of some impairment. The hatched areas on the charts indicate the total percentages of tanks expected to be unable to complete the march becuase of prime-mobility-part deficiencies. It was assumed that the parts deficiencies experienced on the road march would occur at the same mileage frequency as that calculated for the average of these parts observed for tanks of a given age. The height of the bars in the figure reflects the mileage frequency that occurred for the selected parts replacements and again shows the influence of suspension-parts replacements. It will be noted in Fig. F33a that a 20 percent reduction in the average miles per month, 162 to 130 miles per month, did not produce a commensurate change in the percent of tanks unable to complete the march.

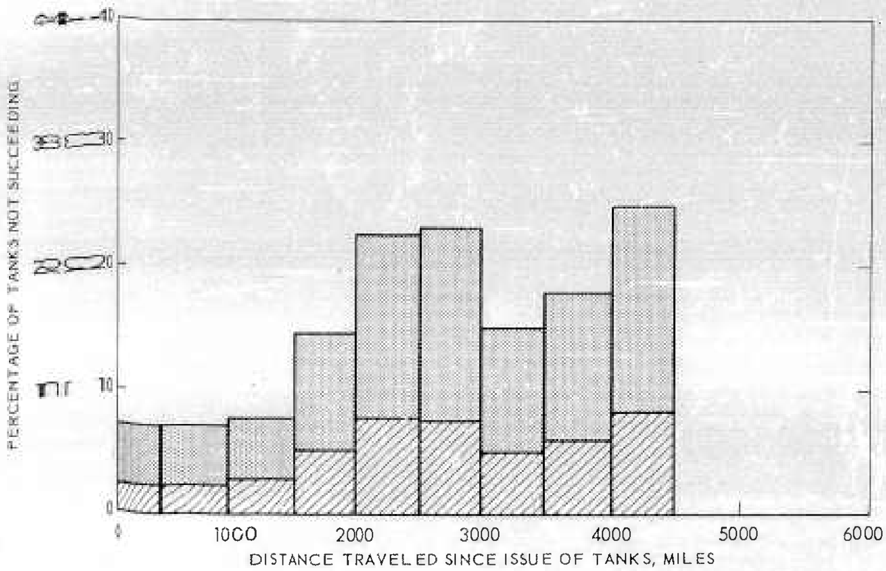
In relation to the above figure it is interesting to note the following excerpt from a CINCUSAREUR message[13] to RUEPDA/DA discussing this company's tanks.

> c. Operational reliability of tanks and effect upon unit operational reliability: all tanks cannot be relied upon to complete a mission requiring a road march of over 35 miles. During a recent readiness test, out of 16 vehicles, 3 vehicles from this company failed to leave the tank park area, another became a drop-out in less than five miles and two others became non-operational during the return road march to home station. Four of these vehicles required extensive repair and parts replacement. Specific component failures were: two fuel pumps, one transmission and one engine.

This message was sent in April 1964, and the average mileage on the tanks at that time was approximately 5600. Relating this mileage to Fig. F33a it is found that 15½ percent or 2½ tanks were expected to be unable to leave the tank park, and 37 percent or approximately 6 tanks would be unable to complete the march. The latter figure includes the tanks that were nonstarters. Although the number of tanks indicated in Fig. F33a as being unable to start the road march and to drop out during the march closely correspond to those actually experienced, it is not implied that such correspondence would always occur. In fact the exact opposite happened during Operation BIG LIFT. This operation took place in Oct–Nov 1963, and at that time the average mileage on B Co's tanks was approximately 5000. On 26 October this company road-marched about 100 miles, and all tanks moved out and completed the march. According to Fig. F33a it would be predicted that 7 percent or 1 tank probably would not have been able to move out and that 10 percent of the company's tanks would have dropped out of the march at that time. The excellent showing made on this march was very likely the result of the quantity and quality of maintenance performed on these tanks just prior to the exercise. If the time allowed for the extensive preparation for this exercise had not been available, B Co probably would have experienced tank dropouts more closely corresponding to the number



a. B Co M60 Tank Performance



b. USAREUR Sample M60 Tank Performance

Fig. F33—Performance of B Co and USAREUR Tank Sample on a Hypothetical 50-Mile Road March

Utilization: —— 130 miles/month – – – 162 miles/month

Dropouts Nonstarters

indicated in Fig. F33a. Returning to their home station after Operation BIG LIFT the company had 9 tanks fail on the 110-mile march whereas only 1 of the other tanks in the battalion became nonoperational. The latter tanks averaged less than 1000 miles of operation. One additional example of this company's road-march experience is given in the CINCUSAREUR message. A readiness test held in December included a road march of 35 miles during which 7 out of the company's 16 tanks became nonoperational. Although the number of tanks that became nonoperational during the latter road marches discussed do not correspond with those indicated by the hypothetical curve, it should be noted that the method was developed to provide indications and is based on a limited number of parts that could cause a tank to become nonoperational. Both the hypothetical and actual road-march experience show the loss of operational reliability that is taking place in B Co's tanks.

COMMENTS OF THE USER

In addition to the above quotation the CINCUSAREUR message contained the following comments on B Co's tanks.

B. The tanks presently assigned are not considered capable of performing their assigned mission for any significant period of time.

D. Change in maintenance workload in the past year: The maintenance workload on these tanks has increased primarily because replacement of one component usually is followed closely by the replacement of a related component, i.e., an engine that is burning excessive oil or failing to develop full power is replaced; in a very short time the transmission requires replacement. (This latter failure may be the result of increased engine power on a worn component or normal wearout of the component.) Additional workload has been experienced in replacing seals, road wheel bearings and road wheel arms that are becoming worn out. Further, many hours are devoted to repair and local fabrication of items such as finders, fender boxes, etc., that are not in the supply system. .

E. Effect of present vehicle condition upon unit readiness: The unreliability of the tanks of this company reduces the combat effectiveness of this battalion by 30 percent. Since these vehicles cannot be relied upon to complete a normal road march and perform a combat type mission they are normally employed in a reserve role where their movement will be held to a minimum and they can receive the maximum support from the organization's maintenance platoon. The additional support required by this company detracts from the support other vehicles in the battalion should receive.

3. In view of the circumstances listed above, it is recommended that the current test which involves only Company B, 1st Bn, 33d Armor be discontinued . . . .

The comments made in paragraph D are substantiated by the recorded maintenance data presented above. All supply items noted here shown an increase in replacement over the last 1500 miles of tank operation, the equivalent of approximately 1 year of operation. It should be noted that for the last 3000 miles the recorded part replacement activity has shown no marked increase and appears to be leveling off. The user's comments in paragraph E regarding the operational reliability of these tanks are an indication of the combat readiness of these tanks, based on the road-march experience and the maintenance data shown above.

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