PSEUDO-RELIABILITY MODEL OF COMBAT TANK SYSTEM*

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ABSTRACT

The effectiveness of an actual combat tank system is analyzed. A measure of effectiveness which includes performance and reliability called *pseudo-reliability is introduced.* A model is introduced to optimize the design of the system in which the system pseudo-reliability is maximized subject to cost constraint. This model is a nonlinear programming problem and is solved by the sequential unconstrained minimization technique (SUMT). A numerical exampl with actual data from the test evaluation of five combat tanks is used to illustrate the model.

INTRODUCTION

The measure of system effctiveness has been a goal of industry and the military as well. One measure has been the system reliability. Another has been the level of performance in that it may not have failed but it is operating at less than peak performance. In the past only one of these measures has been used to evaluate systems, but in this paper an attempt is made to combine both into one measure. This is done and is called pseudo-reliability. To illustrate the resulting optimization model and the method of solution the M60A1E3 combat tank is analyzed. Combat tanks are widely used for mobile defense, destruction of enemy armor formations, reconnaissance and security, close support of infantry, deep penetration and wide envelopment, stability and internal defense assistance operations, etc. [6]. Therefore, the high mission pseudo-reliability of a combat tank is a desirable goal since it is the reliability of the system weighted by its level of performance.

In order to have a high mission pseudo-reliability, we have to develop subsystems having high mean mile between failures (MMBF) early in the design phase. With a limited cost budget for the combat tank system, we are faced with an optimization problem of how to design each subsystem to achieve the most reliable and efficient performance. This optimal design problem, which is a nonlinear programming problem, is solved by employing the sequential unconstrained minimization technique (SUMT) [2, 3, 4].

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BRIEF DESCRIPTION OF THE M60A1E3 COMBAT TANK

The M60A1E3 tank is a full-track-laying, heavily armored combat vehicle operated by a four-man crew consisting of the commander, gunner, loader, and driver. Of the many systems which make up the tank, the power train, suspension, fire control, and communication are considered the four major systems.

The power train consists of the engine, fuel system, air-intake and exhaust system, cooling system, transmission, universal joints, and final drives.

The suspension consists of the track, track support roller,hub, roadwheels, torsion bars, and compensating idler.

The fire control system includes the precision optics and the precise mechanisms to lay the gun on target. Because of the tank's importance in a tactical engagement, the fire control consists of interlocking as well as independent components which reduce non-availability of fire control operations due to failures or battle damage.

Major subsystems of the communication system are the intercommunication set which provides communication between crew members and the radio set which provides communcation between tanks and units.

Detailed descriptions of each subsystem and system can be seen in [6] and the necessary functional descriptions of each are in the following sections.

DEVELOPMENT OF THE PSEUDO-RELIABILITY MODEL

The functional diagram of the combat tank system is shown in Fig. 1. The four major systems; i.e., power train, suspension, fire control, and communication are functionally connected in series. Each is discussed in detail in the following sections.

Power train system

The functional description of the power train can be shown in Fig. 2. To develop the pseudo-reliability model for the power train system, the following assumptions are made:

1) subsystems are statistically independent of one another,
2) subsystems follow the exponential failure distributions where mean mile between failures (MMBF) are $\theta_{p1}, \theta_{p2}, \cdots, \theta_{p7}$, respectively.

The reliability of the subsystem, R_{pi}, is given by

$$R_{pi} = e^{-X/\theta_{pi}} \quad , \qquad i = 1, 2, \cdots, 7, \quad i \neq 3 \tag{1}$$

The subsystem 3 is a complex system and hence we must develop its pseudo-reliability, R_{p3}. To do this we must specify the performance of the system when one or more components fail. This is done as follows:

(i) If all four blowers are working, this subsystem is working with the relative-performance, $\rho_{b1} = 1.0$.

(ii) If any three blowers are working (withone in faileb state), this subsystem is working with the relative-performance, $\rho_{b2} = 0.95$.

(iii) If two blowers are working (with other two in failed state), this subsystem is working with the relative-performance, $\rho_{b3} = 0.50$.

(iv) Otherwise this system is defined to be failed.

These relative-performance factors show the degradation of this subsystem in three different operating conditions. (These factors were agreed upon by the project manager and personnel engaged in the test program of the M60A1E3 tank [5].)

The pseudo-reliabilty of the sub ys stem is then the subsystem state-probability at that degraded level multiplied by its relative-performance factor. This is illustrated by the subsystem 3 composed of four blowers.

Note that the four blowers are identical with MMBF, θ_{p3}. And the reliability and unreliability of a blower is denoted by p_b and q_b respectively, then

$$p_b = e^{-X/\theta_{p3}}, \quad q_b = 1 - p_b \tag{2}$$

The probability of all four blowers working, R_{b1}, is

$$R_{b1} = p_b^4 = e^{-4X/\theta_{p3}} \tag{3}$$

The probability of any three are working, R_{b2}, is

$$R_{b2} = 4p_b^3 q_b = 4e^{-3X/\theta_{p3}}(1 - e^{-X/\theta_{p3}}) \tag{4}$$

The probability of only two are working, R_{b3}, is

$$R_{b3} = 2p_b^2\, q_b^2 = 2e^{-2X/\theta_{p3}}(1 - e^{-X/\theta_{p3}})^2 \tag{5}$$

If subsystem 3 is assumed to be working with peak performance (ideal case) in all casea (i), (ii), and (iii), then the pseudo-reliability of this subsystem, $\hat{R}_{p3}$, is equivalent to the reliability of this subsystem, *i.,e.*,

$$\hat{R}_{p3} = R_{p3} = \sum_{i=1}^{3} R_{bi} \tag{6}$$

However, if the efficiency factors are taken into consideration, we expect that the effectiveness of this subsystem will have smaller values than R_{p3}. By defining the expected performance factor of subsystem 3, ρ_b, as

$$\rho_b = \frac{\sum_{i=1}^{3} \rho_{bi}\, R_{bi}}{R_{p3}} \tag{7}$$

the pseudo-reliability of subsystem 3, $\hat{R}_{p3}$, can be expressed by

$$\hat{R}_{p3} = \rho_b R_{p3} = \sum_{i=1}^{3} \rho_{bi} R_{bi} \tag{8}$$

Using eqs. (1) and (8), the pseudo-reliability of the power train system, R_p, is given by

$$\hat{R}_p = \left(\prod_{\substack{i=1 \\ i \neq 3}}^{7} R_{pi} \right) \hat{R}_{p3}$$

$$= e^{-X \sum_{\substack{i=1 \\ i=3}}^{7} \left(\frac{1}{\theta_{pi}}\right)} \left[\sum_{i=1}^{3} \rho_{bi} R_{bi} \right] \tag{9}$$

where $\rho_{b1}=1.0$, $\rho_{b2}=.95$, $\rho_{b3}=.50$, and R_{bi}, $i=1,2,3$ are given by egs. (3) through (5). Note that the relative-performance factors of subsystems 1, 2, 4, 5, 6, and 7 are assumed to be unity respectively. Hence, the pseudo-reliabilities of these subsystems are reduced to their respective reliabilities.

Suspension system

The suspension system is shown in Fig.3. With the same assumptions of independency and exponential failure distribution as made for the power train system, the reliabilities of subsystems 1, 2, and 8 are given by

$$R_{si}=e^{-X/\theta_{si}},\quad i=1,2,8 \tag{10}$$

and the reliabilities of subsystems 3 and 5 are given by

$$R_{si}=e^{-4X/\theta_{si}},\quad i=3,5 \tag{11}$$

For sybsystem 4, the relative-performance factors are:

(i) If all eight torsion bars are working, this subsystem is working with the relative-performance factor, $\rho_{t1}=1.0$.

(ii) If any seven torsion bars are working (with one in failed state), this subsystem is working with the relative-performance factor, $\rho_{t2}=0.75$.

(iii) If any six torsion bars are working (with other two in failed state), this subsystem is working with the relative-performance factor, $\rho_{t3}=0.5$.

(iv) Otherwise, this subsystem is defined to be failed. Note that eight torsion bars are identical and let MMBF be θ_{s4}. Denoting p_t and q_t the reliability and unreliability of a torsion bar respectively,

$$p_t=e^{-X/\theta_{s4}},\quad q_t=1-p_t \tag{12}$$

Then the probability of all eight torsion bars are working, R_{t1}, is

$$R_{t1} = \binom{8}{8}\ p^8\ q_t^0=p_t^8=e^{-8X/\theta_{s4}} \tag{13}$$

The probability of any seven torsion bars are working (with one in failed state), R_{t2}, is

$$R_{t2} = \binom{8}{7}\ p_t^7\, q_t=8p_t^7q_t=8e^{-7X/\theta_{s4}}(1-e^{-X/\theta_{s4}}) \tag{14}$$

The probability of any six torsion bars are working (with other two in failed state), R_{t3}, is

$$R_{t3} = \binom{8}{6}\ p_t^6\ q_t^2=28p_t^6\ q_2{}^t=28e^{-6X/\theta_{s4}}(1-e^{-X/\theta_{s4}})^2 \tag{15}$$

By employing relative-performance factors, the pseudo-reliability of subsystem 4, $\hat{R}_{s4}$, becomes

$$\hat{R}_{s4} = \sum_{i=1}^{3} \rho_{ti}R_{ti} \tag{16}$$

The same functional descriptions hold for subsystem 6 as for subsystem 4. Hence, the pseudo-reliability of subsystem 6, R_{s6}, can be given by

$$\hat{R}_{s6} = \sum_{i=1}^{3} \rho_{ri}R_{ri} \tag{17}$$

where $\rho_{r1}=1.0$, $\rho_{r2}=.75$, and $\rho_{r3}=.50$,

$$R_{r1}=e^{-8X/\theta_{s6}} \tag{18}$$

$$R_{r2}=8e^{-7X/\theta_{s6}}(1-e^{-X/\theta_{s6}}) \tag{19}$$

$$R_{r3}=28e^{-6X/\theta_{s6}}(1-e^{-X/\theta_{s6}}) \tag{20}$$

The relative-performance factors for subsystem 7 are as follows: For the left-SR's-assembly;

(i) If all three left-SR's are working, the left-SR's assembly is working with the relative-per formance factor, $\rho_{l1}=1.0$.

(ii) If any two left-SR's are working (with one in failed state), the left-SR's-assembly is working with the relative-performance factor, $\rho_{l2}=.75$.

(iii) Otherwise, the left-SR's-assembly is defined to be failed. The same is true for the right-SR's-assembly. Note that six support rollers are identical and let MMBF be θ_{s7}. Let p_l and q_l the reliability and unreliability of a support roller respectively,

$$p_l=e^{-X/\theta_{s7}},\quad q_l=1-p_l \tag{21}$$

The probability of all three left-SR's working, R_{l1}, is

$$R^{l}_{1} = \binom{3}{3}\ p_l^3q_l^0=p_l^3=e^{-3X/\theta_{s7}} \tag{22}$$

The probability of any two left-SR's working (with one in failed state), R_{l2}, is

$$R_{l2} = \binom{3}{2}\ p_l^2q_l=3p_l^2q_l=3e^{-2X/\theta_{s7}}\ (1-e^{-X/\theta_{s7}}) \tag{23}$$

By employing relative-performance factors, the pseudo-reliability of the left-SR'sassembly, $\hat{R}_l$, becomes

$$\hat{R}_l=\sum_{n=1}^{2}\rho_{li}R_{li} \tag{24}$$

where $\rho_{l1}=1.0$, $\rho_{l2}=.75$.

Since the pseudo-reliability of the right-SR's assembly is identical with $\hat{R}_l$, the pseudo-reliability of the subsystem 7, $\hat{R}_{s7}$, is

$$\hat{R}_{s7}=\hat{R}_l^2$$

$$=[\sum_{i=1}^{2}\rho_{li}R_{li}]^2 \tag{25}$$

Using eqs. (10), (11), (16), and (25), the pseudo-reliability of the suspesnion system, $\hat{R}_s$, is given by

$$\hat{R}_s=(\prod_{\substack{i=1\\ i\neq 4,6,7}}^{8} R_{si})\ \hat{R}_{s4}\hat{R}_{s6}\hat{R}_{s7} \tag{26}$$

Fire control system

The fire control system is shown in Fig. 4. With the independency and exponential distribution assumptions for subsystems, the relative-perfornance factors of the system are as follows: When subsystem 1 is working;

(i) If subsystems 2 and 3 are working (regardless of subsystems 4 and 5's function), the system is working with the reative-performance factor, $\rho_{f1}=1.0$.

(ii) If subsystems 2 and 4 are working with subsystems 3 in failed state (regardless of subsystem 5's function), the system is working with the relative-performance factor, $\rho_{f2}=.90$.

(iii) If subsystem 5 is working either with subsystem 2 in faileb state (regardless of subsystems 3 and 4's function) or with subsystems 3 and 4 in failed state (regardless of subsystem 2's function), the system is working with the relative-performance factor, $\rho_{f3}=.60$.

When subsystem 1 is down;

(iv) Description is identical with (i) but $\rho_{f4}=.50$.

(v) Description is identical with (ii) but $\rho_{f5}=.45$.

(vi) Description is identical with (iii) but $\rho_{f6}=.30$.

Let E_i, $i=1,2,\cdots,6$, be events of the above six operative functioal states, (i) through (vi), of the fire control system. Denote the probability of the occurrence of E_i, $P(E_i)$, by

$$P(E_i)=R_{fi},\ \ i=1,2,,6 \tag{27}$$

Further, let C_i, $i=1,2,3,4,5$, be an event that subsystem i is functioning and $\bar{C}_i$ be its complementary event. Denote the probability of the occurence of $C_i, P(C_i)$, by

$$P(C_i)=p_i,\ \ i=1,2,3,4,5 \tag{28}$$

and $p(\bar{C}_i)$ by

$$p(\bar{C}_i)=q_i,\ \ i=1,2,3,4,5 \tag{29}$$

Then

$$p_i=e^{-X/\theta_{fi}},\ \ q_i=1-p_i,\ \ i=1,2,\cdots,5 \tag{30}$$

According to functional description of this system and by eqs. (27) and (30),

$$R_{f1}=p_1p_2p_3=e^{-X\sum_{i=1}^{3}\frac{1}{\theta_{fi}}} \tag{31}$$

$$R_{f2}=p_1p_2p_4q_3=e^{-X\sum_{i=1,2,4}\frac{1}{\theta_{fi}}}(1-e^{-X/\theta_{f3}}) \tag{32}$$

$$\begin{aligned}R_{f3}&=p_1p_5[q_2(p_3+p_4q_3)+q_3q_4]\\&=e^{-X\sum_{i=1,5}\frac{1}{\theta_{fi}}}[(1-e^{-X/\theta_{f3}})(1-e^{-X/\theta_{f4}})+(1-e^{-X/\theta_{f2}})\\&\quad\{e^{-X/\theta_{f3}}+e^{-X/\theta_{f4}}(1-e^{-X/\theta_{f3}})\}]\end{aligned} \tag{33}$$

$$R_{f4}=q_1p_2p_3=e^{-X\sum_{i=2}^{3}\frac{1}{\theta_{fi}}}(1-e^{-X/\theta_{f1}}) \tag{34}$$

$$R_{f5}=q_1p_2p_4q_3=e^{-X\sum_{i=2,4}\frac{1}{\theta_{fi}}}(1-e^{-X/\theta_{f1}})(1-e^{-X/\theta_{f3}}) \tag{35}$$

$$\begin{aligned}R_{f6}&=q_1p_5[q_3q_4+q_2(p_3+p_4q_3)]\\&=e^{-X/\theta_{f5}}(1-e^{-X/\theta_{f1}})[(1-e^{-X/\theta_{f3}})(1-e^{-X/\theta_{f4}})+(1-e^{-X/\theta_{f2}})\\&\quad\{e^{-X/\theta_{f3}}+e^{-X/\theta_{f4}}(1-e^{-X/\theta_{f3}})\}]\end{aligned} \tag{36}$$

The functional descriptions given by (i) through (vi) and its reliability given by R_{fi}, $i=1,2,\cdots,6$ can be derived by Bayes' theorem [1,4].

Let an event of the system success be denoted by S, and the probability of the system success, $P(S)$. Using subsystem 1 as the key subsystem

$$\begin{aligned} P(S) &= P(S|C_1)P(C_1)+P(S|\bar{C}_1)P(\bar{C}_1) \\ &= P[\{C_2\cap(C_3\cup C_4)\}\cup\{C_5\}]P(C_1)+P[\{C_2\cap(C_3\cup C_4)\}\cup\{C_5\}]P(\bar{C}_1) \\ &= [p_2(p_3+p_4-p_3p_4)+p_5-p_2p_5(p_3+p_4-p_3p_4)p_1 \\ &\quad +[p_2(p_3+p_4-p_3p_4)+p_5-p_2p_5(p_3+p_4-p_3p_4)]q_1 \end{aligned} \tag{37}$$

Rearranging terms in the bracket in eq. (37) yields

$$\begin{aligned} P(S) &= p_1p_2p_3+p_1p_2p_4q_3+p_1p_5[q_3q_4+q_2(p_3+p_4q_3)] \\ &\quad +q_1p_2p_3+q_1p_2p_4q_3+q_1p_5[q_3q_4+q_2(p_3+p_4q_3)] \\ &= \sum_{i=1}^{6} R_{fi} \end{aligned} \tag{38}$$

By employing relative-performance factors, the pseudo-reliability of the fire control system, $\hat{R}_f$, becomes

$$\hat{R}_f=\sum_{i=1}^{6} \rho_{fi}R_{fi} \tag{39}$$

where R_{fi}, $i=1,2,\cdots,6$ are given by eqs. (31) through (36), and

$\rho_{f1}=1.0$, $\rho_{f2}=.90$, $\rho_{f3}=.60$, $\rho_{f4}=.50$, $\rho_{f5}=.45$, $\rho_{f6}=.30$.

Communication system

The communication system can be shown in Fig. 5. The reliability of sybsystem 1, R_{c1} is

$$R_{c1}=e^{-X/\theta_{c1}} \tag{40}$$

Note that the failure of sybsystem 2 does not make the system inoperable, however, it makes the system approximately 75% inefficient. Assigning the degradation factor, $d=.75$, the pseudo-reliability of subsystem 2, $\hat{R}_{c2}$, becomes

$$\hat{R}_{c2}=1-d(1-e^{-X/\theta_{c2}}) \tag{41}$$

Hence, the pseudo-reliability of the communication system, $\hat{R}_c$, is

$$\begin{aligned} \hat{R}_c &= R_{c1}\hat{R}_{c2} \\ &= e^{-X/\theta_{c1}}[1-d(1-e^{-X/\theta_{c2}})] \end{aligned} \tag{42}$$

Systems Pseudo-Reliability

The pseudo-reliability of the combat tank system, $\hat{R}_T$, is expressed as the product of four system pseudo-reliabilities

$$\hat{R}_T=\hat{R}_p\hat{R}_s\hat{R}_f\hat{R}_c \tag{43}$$

where $\hat{R}_p$, $\hat{R}_s$, $\hat{R}_f$, and $\hat{R}_c$ are given by eqs. (9), (26), (39), and (42) respectively.

COST STRUCTURE

Most systems and particularly the thank system is constrained to be built within a given budget limit. To accomplish this, the cost function of the tank system must be formulated.

Two categories of costs are considered:

(i) cost of design and manufacture of each subsystem ij, $C_D(\theta_{ij})$ as a function of the mean miles between failure (MMBF), θ_{ij},

(ii) cost of maintenance of subsystem ij, $(C_M(\theta_{ij}))$.

The two categories of costs for each of the subsystem have the functional relationship of the MMBF, θ_{ij}, as shown in Fig.6. The functional forms are given by

$$(C_D)_{ij}=\alpha_{ij}(\theta_{ij})^{\beta_{ij}}, \qquad \begin{array}{l} i=\text{system index} \\ j=\text{subsystem index within a system} \end{array} \tag{44}$$

$$(C_M)_{ij}=\frac{\gamma_{ij}}{\theta_{iij}}, \tag{45}$$

where the cost coefficients for each subsystem α_{ij}, β_{ij}, and γ_{ij} are constants which must be determined and are based on the available past experience, engineering judgement, and the present level of MMBF.

The two categories of costs at each system level are given below: The costs of power train system;

$$(C_D)_p=\sum_{j=1}^{7}(C_D(\theta_{pj})) \tag{46}$$

$$(C_M)_p=\sum_{\substack{j=1 \\ j\neq 3}}^{7}(C_M(\theta_{pj}))+4(C_M(\theta_{p3})) \tag{47}$$

Note that $C_M(\theta_{p3})$ is multiplied by four since we have four identical blowers. For the costs of suspension system we have;

$$(C_D)_S=\sum_{j=1}^{8}(C_D(\theta_{Sj})) \tag{48}$$

$$(C_M)_S=\sum_{j=1,2,8}(C_M(\theta_{Sj}))+4\sum_{j=3,5}(C_M(\theta_{Sj}))+8\sum_{j=4,6}(C_M(\theta_{Sj}))+6(C_M(\theta_{S7})) \tag{49}$$

For $j=3,4,5,6,7$, $(C_M(\theta_{Sj}))$ are multiplied by the number of identical components respectively.

The costs of fire control system are

$$(C_D)_f=\sum_{j=1}^{5}(C_D(\theta_{fj})) \tag{50}$$

$$(C_M)_f=\sum_{j=1}^{5}(C_M(\theta_{fj})) \tag{51}$$

Finally the costs of communication system are

$$(C_D)_c=\sum_{j=1}^{2}(C_D(\theta_{cj})) \tag{52}$$

$$(C_M)_c=\sum_{j=1}^{2}(C_M(\theta_{cj})) \tag{53}$$

Hence, the total cost of the tank system, C_T, can be given by

$$C_T=\sum_{k=p,s,f,c}[(C_D)_k+(C_M)_k] \tag{54}$$

PSEUDO-RELIABILITY OPTIMAL ALLOCATION PROBLEM

The optimization problem resulting from the above discussion is to maximize the pseudo-reliability of the system for a given mission distance (or period) within a limited cost budget for the system. Specifically, the allocation problem can be defined as

maximize $\hat{R}_T$

subject to $C_T \leq C_0$ (55)

$\theta_{ij} \geq \theta_{ij}^o$, i = system index (56)

j = subsystem index

where $\hat{R}_T$ is given by eq. (43), C_0 represents the upper limit for the cost and is a constant, and θ_{ij}^o's are lower limits for θ_{ij}'s and are constants.

The allocation problem, then, is to determine optimal subsystems parameters, θ_{ij}'s, simultaneously, which yield the optimal system pseudo-reliability.

Since both the pseudo-reliability and cost function arenonlinear, the seq uential unconstrined minimization technique (SUMT) which incorporates the Hooke and Jeeves pattern search and heuristic programming [3] is employed to solve this allocation problem.

NUMERICAL EXAMPLE

Problem Formulation

Assume a day's mission distance of the combat tank is 100 miles, i.e.,

$$X=100 \text{ miles} \tag{57}$$

and the cost allowed for the tank system is limited to $\$300(10^3)$, i.e.,

$$C_o=\$300(10^3) \tag{58}$$

In Table 1, numerical values used for cost coefficients, α_{ij}, β_{ij}, and γ_{ij}, and lower limits of $\theta_{ij}, \theta_o^{ij}$, are given. Note that the initial values for θ_{ij}'s are obtained from actual actual test data on five tanks in reference [5] and are incorporated in determining the cost coefficients.

Using these values, the problem is, then, to determine θ_{ij}'s which maximize the pseudo-reliability of the tank system given by eq. (43) under the constraints given by eqs. (55) and (56).

Problem Definition for the SUMT Program

The nonlinear programming problem in the SUMT format is stated as follows:

minimize

$$f(\theta)=-\hat{R}_T \tag{59}$$

subject to

$$g_j(\theta_{pj}(=\theta_{pj}-\theta^o_{pj}>0, \quad j=1,2,\cdots,7$$
$$g_{j+7}(\theta_{Sj})=\theta_{Sj}-\theta^o_{Sj}>0, \quad j=1,2,\cdots,8$$
$$g_{i+15}(\theta_{fi})=\theta_{fj}-\theta^o_{fj}>0, \quad j=1,2,\cdots,5 \tag{60}$$
$$g_{j+20}(\theta_{c}\cdot)=\theta_{ci}-\theta^o_{cj}>0, \quad j=1,2$$
$$g_{23}(\underline{\theta})=C_0-C_T>0$$

where θ denotes a column vector, $\underline{\theta}=(\theta_{p1}, {}_{p2}, \cdots, \theta_{c2})^T$.

Results

The starting values and the final optimal values for the θ_{ii}'s, the two categories of costs, the total cost, and the pseudo-reliability of tank are shown in Table 2. Values for θ_{ii}'s were obtained from test data on five tanks in [5] and were used as starting values which were adjusted to improve the optimal pseudo-reliabilities. Under the assumed cost functiens, the initial leuel of MMBF values were changed to improve the pseudo-reliability from .62240 to .69389. For this increase, hte MMBF of the the track, the roadwheel#1 and 6, and the roadwheel#2, 3, 4, and 5 needed the most improvement; that is (see Table 2) from 1300→2513, 5900→12110, and 8000→11730 miles respectively. The additional costs of design and manufacture for these subsystems were; 9.4→24.8, 7.61→20.8, and 6.99→11.9 (10^3\$) respectively, whereas costs of maintenance wasreduced; 6.15→.318, 2.03→.99, and 2.4→1.64 respectively. The reverse effcts can be seen on the blower and the air cleaner subsystem. As a result of an approximate 10% improvement in the pseudo-reliability, total cost of design and manufacture has been increased from 236.3(10^3\$) to 269.2 (10^3\$) while total cost of maintence has been decreased from30.58 (10^3\$) to 30.27 (10^3\$)

DISCUSSION

The pseudo-reliabilityof a system, which is the reliability of a system weighed by the relative-performance factor of a system, is introduced. It appears to be a more practical measure of the system effectiveness than reliability whenever the level of performance is of primary concern as is the case for the combat tank system. Through the process of maximizing the pseudo-reliability of a system within cost constraints we are provided with information on how much of the resources in terms of design effort and cost need to be allocated to each subsystem. This informations is most useful during the design phase of the project.

The SUMT technique with the aid of Hooke and Jeeves pattern search appears to be an efficient technique for solving complex nonlinear models.

Using the actual θ_{ij}'s as starting points and the assumed cost functions we note that the optimal values of θ_{ij} changed a good deal where the starting psuedo-reliability of the system was .62 and the final or optimal value was .69. This represent an approximate 10% improvement in performance.

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Table 1. Numerical values for α_{ij}, β_{ij}, γ_{ij}, and θ^0_{ij}

system	sysem index i	subusystem index j	β_{ij}	α_{ij} $[\frac{(10^3\$)(\text{failure})}{(\text{mile})}]$	γ_{ij} $[\frac{(10^3\$)(\text{mile})}{(\text{failure})}]$	θ^0_{ij} [mile]
		1		0.00014	5350	1500
		2		0.00007	4000	1500
		3		0.000005	6000	6000
power train	p	4	1.5	0.000002	7000	10000
		5		0.000014	8000	5000
		6		0.00017	2000	1500
		7		0.00007	3500	2500
		1		0.00005	3000	3500
		2		0.00043	800	1000
		3		0.000006	14400	15000
suspension	s	4	1.4	0.000002	15000	30000
		5		0.00004	3000	5000
		6		0.000024	24000	6500
		7		0.000043	1500	5500
		8		0.000013	8750	9000
		1		0.00009	3300	1700
		2		0.000013	12000	5000
fire control	f	3	1.6	0.000027	4500	2000
		4		0.000009	6000	5000
		5		0.000001	23800	15000
communication	c	1	1.4	0.00005	12000	7000
		2		0.00007	4000	4000

Table 2. SUMT Results

System index i	Subsystem index j	Starting values			Optimal results		
		θ_{ij}	$(C_D)_{ij}$	$(C_M)_{ij}$	θ_{ij}	$(C_D)_{ij}$	$(C_M)_{ij}$
	1	2670	19.32	2.00	2996	22.96	1.79
	2	2670	9.66	1.50	3764	16.17	1.06
	3	12000	6.57	2.00	8868	4.18	2.71
p	4	24000	7.44	0.29	16320	4.17	0.43
	5	8000	10.02	1.00	7345	8.81	1.09
	6	2000	15.21	1.00	2662	23.35	0.75
	7	3400	13.88	1.03	3780	16.27	0.93
	1	5000	7.54	0.60	6284	10.39	0.48
	2	1300	9.84	0.62	2513	24.76	0.32
	3	24000	8.14	2.40	28157	10.18	2.05
s	4	50000	7.58	2.40	39251	5.40	3.06

	5	5900	7.61	2.03	12110	20.82	0.99
	6	8000	6.99	2.40	11729	11.94	1.64
	7	7000	10.39	1.29	8087	12.72	1.11
	8	12500	7.07	0.70	11351	6.18	0.77
	1	2200	20.05	1.50	1949	16.52	1.69
	2	6000	14.42	2.00	5276	11.74	2.28
f	3	3000	9.88	1.50	2660	6.04	2.04
	4	6000	9.98	1.00	5088	7.66	1.18
	5	24000	10.19	0.99	15825	5.24	1.50
c	1	8000	14.56	1.50	7384	13.02	1.63
	2	4800	9.97	0.83	5040	10.68	0.79
Total cost	C_T	266.89			299.45		
Pseudo-reliability	R_T	0.622			0.694		

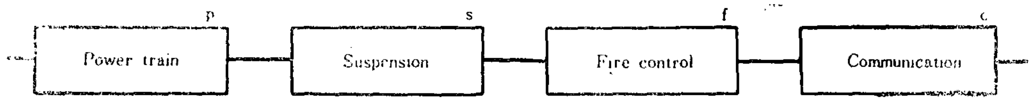
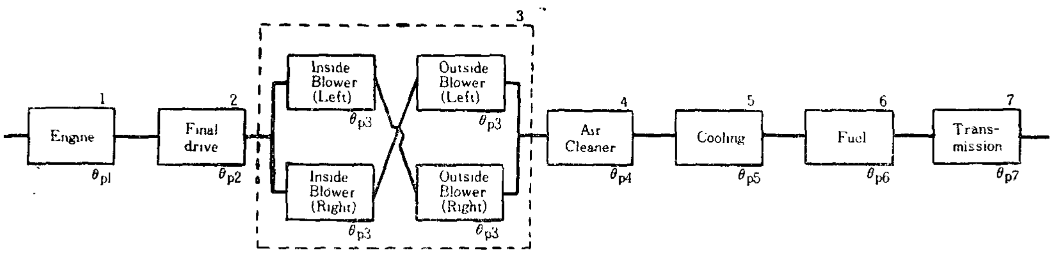


Fig.1. Functional Diagram of Combat Tank System



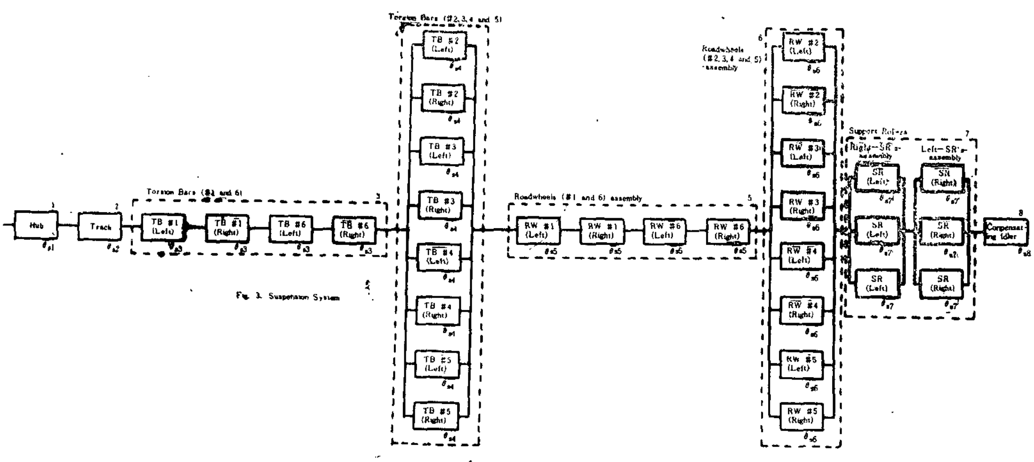


Fig. 3. Suspension System

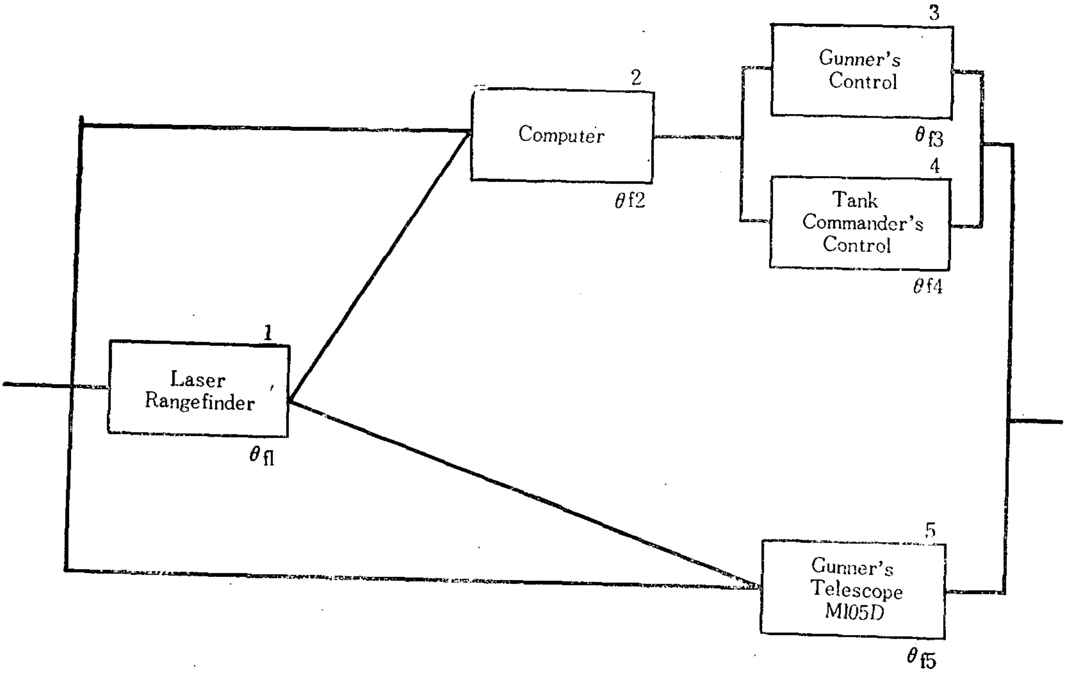


Fig.4. Fire Control System

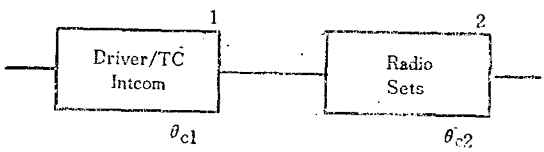


Fig.5. Communication System

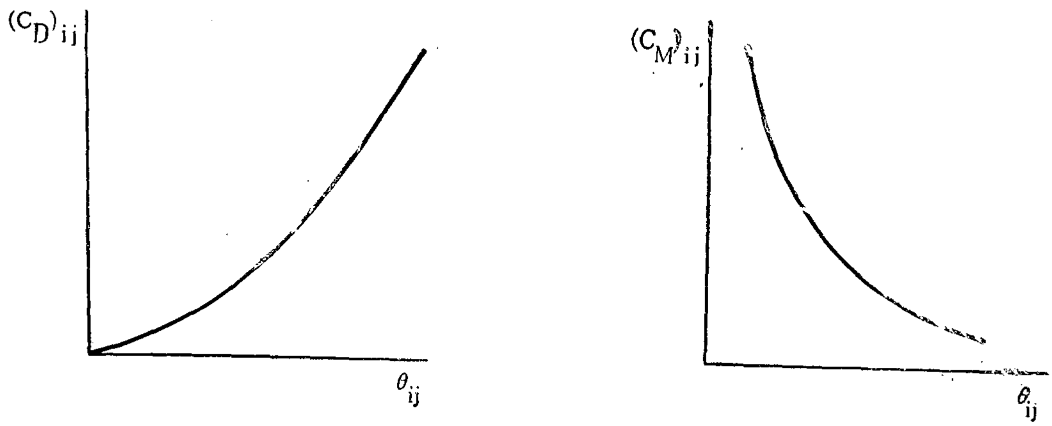


Fig.6. Costs versus MMBF of sybsystem *ij*