A COMPUTERIZED LCC/ORLA METHODOLOGY

J. T. Henderson, P.E.

Key Words: Life Cycle Costs, Optimum Repair Level, Maintenance Strategy

Abstract

This paper describes the effort expended by Sandia Laboratories in developing CDC6600 computer programs for Optimum Repair Level Analysis (ORLA) and Life Cycle Cost (LCC) analysis.

Investigation of the three repair-level strategies referenced in AFLCM/AFSCM 800-4 (base discard of subassemblies, base repair of subassemblies, and depot repair of subassemblies) was expanded to include an additional three repair-level strategies (base discard of complete assemblies and, upon shipment of complete assemblies to the depot, depot repair of assemblies by subassembly repair, and depot repair of assemblies by subassembly discard).

The expanded ORLA was used directly in an LCC model that was procedurally altered to accommodate the ORLA input data. Available from the LCC computer run was an LCC value corresponding to the strategy chosen from the ORLA.

Introduction

CDC6600 computer programs were developed by Sandia Laboratories in response to Contract Data Requirement List (CDRL) ORLA requirements in a Base and Installation Security System (BISS) contract with the Air Force, Electronic Systems Division. Guidelines for the ORLA were initially obtained from Air Force document AFLCM/AFSCM 800-4, entitled "Optimum Repair Level Analysis (ORLA)." These guidelines were used with minor alteration in preliminary studies for the BISS. In subsequent studies involving substantial quantities of non-repairable hardware and hardware that could be logically considered for depot repair as an assembly, a more complex model of the ORLA plus a LCC extension to the ORLA were developed.

An Overview of the BISS Program

The BISS Program encompasses the technology and hardware necessary to offer a high level of security for Department of Defense installations world-wide. In general the BISS detects hostile activity at or near the perimeter of an installation and processes this activity for suitable display to base security personnel in the form of an alarm. Based on the assessment of the data contained in the alarm, proper action can be taken against the hostile activity.

This detection and assessment problem is by no means trivial and many types of sensors (and related technologies) are required. The sensor data, to be useful, must possess a high level of discrimination and security (including tamper detection). The processing of the data must not degrade the aforementioned characteristics, and the system must contain a degree of built-in error detection capability.

The concept of maintenance on the BISS Program includes maintenance personnel at the individual bases and maintenance personnel at several higher level installations called depots. Items and equipment for repair and diagnostics respectively are proportional to the items to be repaired or discarded at failure at each location. These factors as well as many others including shipping cost, spare provisioning, personnel training, etc., react with one another to yield the maintenance constraints associated with a given maintenance philosophy.

The Intent of AFLCM/AFSCM 800-4

AFLCM/AFSCM 800-4 lists two desirable aspects of performing an ORLA. The first is a systematic approach to treating <u>all possible</u> maintenance concepts. The second is the <u>timely</u> application of the approach to all phases of analysis. Implied in both features is the possibility that changes in design, although requiring greater development and acquisition costs, might well be substantiated by a decreased life cycle cost.

Thus, the consideration of a particular maintenance concept cannot be omitted just because the current design doesn't quite conform.

The Computerized ORLA

The original version of the ORLA computer program very closely followed the equations, terms and definitions of AFLCM/AFSCM 800-4. This program was used to determine the repair-level decisions for the Small Permanent Communications and Display Segment (SPCDS) of the BISS.

It was not until a subsequent study was started on the BISS Seismic Point Sensors that it was determined that the number of repair-level options should be expanded from three to six. In addition, it was determined to be desirable that the ORLA input data be used in a subsequent Life Cycle Cost calculation. To facilitate this, the equations and format of the ORLA were modified to a LCC format. These changes as well as other minor modifications dictated a restructuring of the ORLA computer program. The remainder of this paper will address the new ORLA and its companion LCC computer program.

Decisions Available

The three decisions retained from AFLCM/AFSCM 800-4 were:

1) Discard a subassembly at the usage site (base) at failure occurrence, this option is symbolized by (T)
2) Repair a subassembly at the base at failure occurrence, this option is symbolized by (F)
3) Repair a subassembly at a higher level installation (depot) at failure occurrence, this option is symbolized by (DD)

Implied within these decisions in all cases is the isolation of faults to the subassembly at the base. These decisions did not consider the possibility that the cost of isolating failures to the subassembly at the base level might be significant in terms of equipment and/or maintenance skill levels. Three additional decisions were considered that encompassed the aforementioned possibility. These decisions were:

4) Depot level assembly repair by subassembly repair at failure, this option is symbolized by (DF)
5) Depot level assembly repair by subassembly discard at failure, this option is symbolized by (DT)
6) Base level assembly discard at failure, this option is symbolized by (TT)

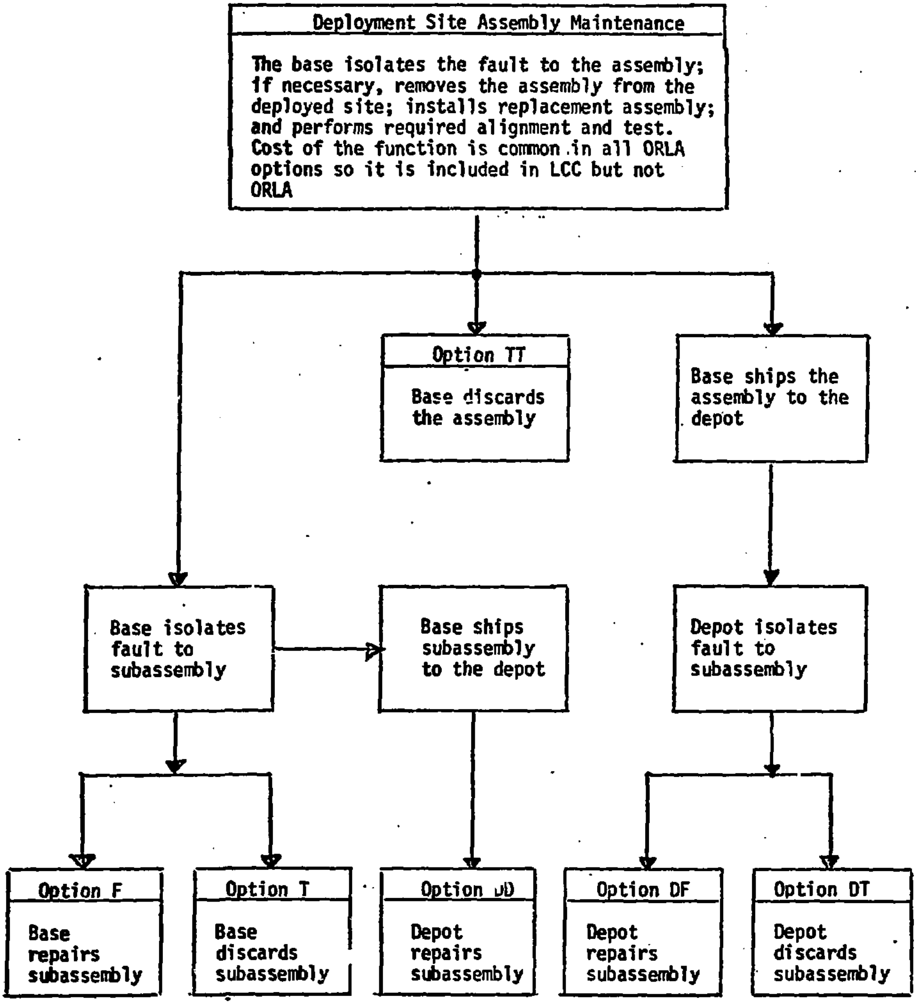
These decisions are summarized in flow chart form in Figure 1. An overall strategy for optimum maintenance might consist of various combinations of these six decisions for a given system. Care must be taken, however, when comparing alternatives so as not to cross decision flow chart lines for a given assembly. Referring to Figure 1, it can be seen that three paths are available for repair-level. If a mixture of decisions at the subassembly level causes more than one path to be implied for a given assembly, one must first pick the overall optimum path. This can be done by comparing the summation of the subassembly cost contributions for each option and selecting the minimum cost path. Once this is done, one must restrict the repair-level choices to those covered by the path containing the lowest total assembly cost. For example, if the assembly is shipped to the depot, one must choose between depot repair or depot discard (Options DF and DT respectively) for all subassemblies even if another option (base discard for example) might be cheaper for a particular subassembly within the given assembly. The computer program logic performs this sorting task automatically and the decisions will be restricted to those that are logically consistent.

A Discussion of the Equations Solved

In the course of assigning values to the six possible options, the computer solves 51 equations. These equations consider the following costs as appropriate for the particular option selected:

FIGURE 1

ORLA OPTION BLOCK DIAGRAM



1) Initial spares cost
2) Packing and shipping cost
3) Base stock level cost
4) Supply management and administrative cost
5) Peculiar Support Equipment (PSE) acquisition and development cost
6) Training (instruction) cost
7) Technical data cost, i.e. cost of technical manuals
8) Equipment maintenance cost, including forms and transaction records
9) Repair materials and replacement cost
10) Depot safety stock
11) Replacement spares cost

Since there are different equations for a given cost item (as a function of the chosen option), it would be illustrative to develop a typical cost item in terms of the six options. The cost item chosen for this development is number 8) above, equipment maintenance cost. The general form for the equations covering cost item eight is:

$$X8(I) = 12 \cdot PIUP \cdot \frac{UR}{MTBF(I)} \cdot NOA(I) \cdot QPA(I) \cdot (TMCX + TR) \cdot CLTX \quad (1)$$

where X refers to the particular option, i.e., T, F, DF, etc. The other terms in the equation are as follows:

- PIUP - Equipment life in years
- UR - Utilization rate, i.e. number of operating hours per month
- MTBF - Mean time between failures for subassembly I
- NOA - Number of operating assemblies (excluding spares), containing subassembly I
- QPA - Number of Ith subassemblies within the assembly containing subassembly I

TMC - Average maintenance manhours per maintenance task

TR - Average manhours to complete maintenance and transaction records

CLT - Fully-loaded labor rate including consumable materials for activity considered

Equation (1) above applies directly, with appropriate substitution of values for the X-labeled items, for options F, DF, DT and T. For option DD, the basic form of equation (1) is assumed with an add-on term of T8(I). This add-on term is necessary to reflect the added costs associated with the fact that the assembly was originally repaired at the base by the substitution of a new subassembly. A minor modification to the original expression is necessary, however, since the recordkeeping associated with the failure will not be duplicated at the depot. To effect this, the term TR is set equal to zero in equation (1) for the depot cost portion of DD8(I). The new equation becomes:

$$DD8(I) = 12 \cdot PIUP \cdot \frac{UR}{MTBF(I)} \cdot NOA(I) \cdot QPA(I) \cdot TMCDD \cdot CLTD + T8(I) \qquad (2)$$

When evaluating the equation to be used with the cost item TT8(I), one finds that the equation is logically always equal to zero. This fact is due to the use of Organizational-level maintenance to arrive at the point of potential entire assembly discard. The assignment to Organizational level is due to the task's being necessary regardless of which maintenance option is ultimately chosen, that is, the ORLA does not treat this since it is common to all possible alternatives. Other cost items such as this will be discussed later under the Life Cycle Cost discussion.

A similar treatment could be given to all other equations required. One could assume a general form of the equation and then modify the equation to fit the physical and functional constraints of the particular option.

Constants for the Equations

The ORLA contains 67 constants in support of its 51 equations. Typical examples would be PIUP, UR, TMCDD, TR and CLTD from equation (1). Of these constants, 36 are classified as long term (revised from time-to-time by the Air Force) and 31 are classified as system level (common for a given system). Since these constants rarely change, they are a part of the computer program proper. Changes to these constants can be effected by the addition of control cards at the card deck input. Other data are input to the computer at card deck input. These variables are broadly defined as assembly and subassembly related.

Sensitivity Analysis

In an effort to meet the intent of AFLCM/AFSCM 800-4 and to allow for modeling of inflation/deflation of costs, the computer program contains a three-level sensitivity analysis. The variables considered for a sensitivity study are 1) item costs and 2) item failure rates. Both of these variables are allowed to vary to 150% and 50% of their values in addition to their nominal input values. This allows for 3 x 3 or 9 different sets of ORLA results. Thus if one felt that the cost of an assembly was controlled by parts that would become less expensive due to competition, one could look at the 0.5 cost printout. With MTBF as a variable, one could model the possibility that the assemblies might become more reliable with increased manufacturing experience or improved screening. Likewise, if experience shows that failures are occurring more frequently than predicted, one could refer to the 0.5 MTBF printout.

An ORLA Printout

Figure 2 represents a typical printout for one selected value of MTBF, the nominal or 1.0 value and for three values of CAL (item cost), 0.5, 1.0 and 1.5. Several comments are in order for the content of this printout:

Figure 2

TABLE I

1.0MTBF

COSTS IN DOLLARS

CDVS(CMU)

	(I) BASE DISCARDS SUBASSEMBLY			(II) BASE DISCARDS ASSEMBLY			(F) BASE REPAIRS SUBASSEMBLY			(DD) DEPOT REPAIRS SUBASSEMBLY -BASE SHIPS TO DEPOT-		
	1.0CAL	1.5CAL	0.5CAL	1.0CAL	1.5CAL	0.5CAL	1.0CAL	1.5CAL	0.5CAL	1.0CAL	1.5CAL	0.5CAL
VIDEO PRES. DETECTOR	42622	51036	34238	------	------	------	58707	58800	58614	30592	30832	30352
ANNUNCIATOR	27033	27815	26251	------	------	------	42919	42928	42910	28375	28397	28353
CAMERA DECODING	35213	39654	30772	956034	1419629	492439	103096	103146	103047	33396	33523	33269
LAMP DIM $ VOLT REG	32695	36223	29166	------	------	------	79096	79135	79057	33173	33274	33072
POWER SUPPLY 1	38637	44564	32711	------	------	------	418773	418839	418708	76129	76299	75960
POWER SUPPLY 2	45067	53827	36307	------	------	------	418843	418940	418746	77818	78069	77568
	221267	253089	189445	956034	1419629	492439	1121435	1121787	1121083	279484	280394	278573

	(DF) DEPOT REPAIRS SUBASSEMBLY -DEPOT ISOLATES FAULT-			(DT) DEPOT DISCARDS SUBASSEMBLY			LEAST COST DECISIONS (VARIABLE CAL)			LEAST COST-1CAL	FROM TABLE I 1CAL
	1.0CAL	1.5CAL	0.5CAL	1.0CAL	1.5CAL	0.5CAL	1.0CAL	1.5CAL	0.5CAL		
VIDEO PRES. DETECTOR	13948	15310	12586	28846	38527	19166	DF	DF	DF	DF	DF
ANNUNCIATOR	9064	9300	8827	9419	10431	8436	DF	DF	DT	DF	DF
CAMERA DECODING	16940	18283	15598	24014	29763	18265	DF	DF	DF	DF	DF
LAMP DIM $ VOLT REG	16005	17072	14938	17341	21908	12773	DF	DF	DT	DF	DF
POWER SUPPLY 1	64327	67835	60819	29399	38788	20011	DT	DT	DT	DT	DT
POWER SUPPLY 2	64355	67878	60833	35056	47263	22836	DT	DT	DT	DT	DT
	184640	195678	173602	144069	186680	101457					

1) Three costs, one for three levels of subassembly cost, are presented for each subassembly.
2) The TT option, Base Discards Assembly, contains only one cost. This cost is compared for decision purposes to the summation of the subassembly costs for the other options.
3) The "Least Cost Decisions" heading details the repair-level decisions for 1.0 MTBF. It should be noted that two subassembly decisions changed from DF (Depot Repair after Depot Isolation) to DT (Depot Discard) as a function of the subassembly cost varying to 0.5 of nominal value.
4) Although the computer logic was not exercised, it should be noted that the recommended decisions always followed physically achievable paths, i.e., DT and DF are in the same logic path in Figure 1.
5) The recommended decision is to perform fault isolation at the base to the assembly level, i.e., the CDVS. The entire CDVS is then replaced at the base and the faulty CDVS is forwarded to the depot for repair. Once at the depot, the CDVS is fault isolated to the subassembly level and depending on the particular failure, the faulty subassembly is either repaired or discarded.

Another comment with respect to the sensitivity analysis is appropriate at this time...it truly is a hedge against the future. If the decisions were relatively close and one suspected a shift in the cost or MTBF, one could check the overall effect by scanning the appropriate table and column. The sensitivity analysis is also good for checking the worst case consequences of making uniform decisions, e.g., converting a singular discard action to a repair if all other subassembly dispositions were repair.

A Discussion of Life Cycle Costs

A review of the 11 cost items treated by the ORLA would indicate that those cost items are the items that would change as a function of the particular repair-level decision chosen.

There is another set of costs and equations that pertain to those costs that would not change as a function of the repair-level decision. These costs are commonly referred to as Organizational-level or LCC costs. A summary of these costs is given below:

1) Cost of technical data exclusive of Technical Orders (TO's), e.g., DD1423 data such as FMECA's, Hazards Analyses, etc.
2) Cost of that portion of the TO's concerned with organizational level maintenance, i.e., maintenance at the Configured Item (CI) discard or replacement level.
3) Site preparation and installation costs, e.g., cabling, supports, etc.
4) Peculiar Support Equipment required for installation and alignment. Also, that PSE associated with CI-level trouble-shooting.
5) Common support equipment acquisition cost where existing base or depot quantities are not sufficient.
6) Training costs associated with CI-level troubleshooting.
7) Initial and continuing costs for Air Force special operator training.
8) Acquisition costs of peculiar training equipment (in addition to the use of CI's or subassemblies of CI's).
9) Maintenance personnel transit time to a site. Preventive (scheduled) maintenance and corrective maintenance associated with non-failed (operating) hardware.
10) ORLA-related (discard) costs associated with non-repairable items. These items were excluded from the ORLA since a repair-level analysis was not needed.
11) Design and development costs of a system, including the costs of Engineering Models, testing and evaluation.
12) Acquisition costs of the system hardware, including testing of follow-on hardware and the associated overall management costs.

The above costs, when added to the aforementioned ORLA costs, yield the Life Cycle Costs associated with a given system deployment.

Obtaining the Life Cycle Costs of an Assembly

A LCC computer program was developed to incorporate the costs mentioned in the last paragraph and the results of the ORLA. It should be noted that the ORLA equations contain amortizing expressions. (Several of these will be discussed later in this paper). For this reason, the results of the ORLA cannot be used directly with the LCC computer program. To allow the ORLA data to be used directly as input to the LCC computer program, one must re-run the ORLA computer program and re-amortize the appropriate costs to the actual decisions chosen. For instance, if test equipment is amortized over all subassemblies, but subsequently two are deemed throwaway, one must re-amortize the test equipment to only those subassemblies to be tested. Once the ORLA has been altered to reflect the actual decisions chosen, the ORLA data can be used directly in the LCC computer program.

Assumptions

Inherent in the ORLA program and in the data are several assumptions. The assumption having the most pronounced effect involves the determination and treatment of non-standard parts, i.e., which parts must be added to the Air Force inventory to support a given design and how their documentation and introduction costs are to be amortized.

Another assumption of lesser consequence is an estimate of the number of part failures associated with each assembly failure. For this analysis a rate of 1.2 failed parts per 1 failed assembly was chosen.

A final example is the assumption that the cost to repair test equipment is negligible. This may be a valid assumption for special designed test equipment utilizing Air Force standard parts but may very well not be a valid assumption for less reliable commercial hardware.

Limitations

The ORLA program is lengthy and very closely approximates the complex problem of determining life cycle costs for many options. It however falls short of the real world in some areas by the very nature of the complexity of the problems modeled. For instance, there are no provisions for cost escalation or de-escalation in labor rates, parts prices, costs shipping, etc. In actuality, parts and labor costs will increase during the life of the BISS hardware for most cases. A noticeable exception are I.C.'s; they have actually maintained the same price or become cheaper. In view of the uncertainties of trying to predict an inflation rate and to assess its impact on each of the variables, all costs in the ORLA reflect 1978 dollars.

The ORLA program contains several equations pertaining to stocking of spare subassemblies and parts. Also contained are pipeline delay times. Although the delay times can be taken at worst case conditions, there is no attempt to add any worst case conditions to the need for spares, i.e., spares are considered always available if stocked at the MTBF-directed failure rate. Confidence limits can be applied for guaranteeing no shortages and the spare parts/subassemblies costs can be added manually if necessary.

New Parts in Inventory

Several of the BISS items of hardware required the introduction of new parts into the Air Force inventory. As a general rule those items that more closely approximated the state-of-the-art in design had more new parts. Equations contained in AFLCM/AFSCM 800-4 do not differentiate between those parts that will likely have a one-time use in a design and those parts that will likely have use by other agencies and designs. In an effort to allow for this, the ORLA makes an assignment of the costs associated with new part documentation and introduction to short-term or full-term amortization depending on the potential for further use. The parts costs are then "weighted" with a value proportional to their use on BISS alone. The useful life of the BISS hardware is 10 years and full-term amortization consists of the full 10 year time base. Short-term amortization has been set at one year.

An example of parts costs that would be amortized over one year is Complementary Output Symmetry Metal Oxide Semiconductors (COSMOS) I.C.'s. Parts costs that would be amortized over 10 years would include special cut crystals and high precision or special-valued resistors.

It is noted that the calculations for new part "weighting" are performed external to the computer program and are input as two variables per subassembly at card input time.

The ORLA also has provisions for allocating the costs of new parts over all subassemblies that use the new part. In this way, a given subassembly will not have to carry the full costs associated with a new part.

Field Peculiar AGE

Each of the repair-location options covered in the ORLA has a potential for a different set of support equipment. After determination of the normal complement of support equipment at bases and depots, one must allocate the additional (peculiar) Aerospace Ground Equipment (AGE) to the subassemblies that it services and only to that equipment. These calculations are made external to the computer program and are input as six variables to the computer program at card deck input.

Conclusion

This overview of the ORLA and LCC computer programs was intended to show the limitations as well as the usefulness of the decisions obtained. The ORLA is a powerful tool in the conceptual design phases through the operational phases.

Although costs associated with changing previous decisions increase as you progress through the design and manufacturing phases, one can have quick access to the life cycle cost differences for any decision chosen.