Estimation Model

for Integrated Logistics Support Cost and Annual Recurrent Expenditure in C3 Projects

ABSTRACT

In defence acquisition and development projects, the costs of Integrated Logistics Support (ILS) and the Annual Recurrent Expenditure (ARE) make up a significant part of the total cost of ownership of each system. Clarity and accuracy in estimating these costs are important for long-term budgeting and decision making. The article provides a model for planners to do a first order estimate of the ILS cost and ARE of a new Command, Control and Communications project as percentages of its capital investment cost. The analysis is based on a set of cost drivers and historical cost data.

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INTRODUCTION

The Ministry of Defence (MINDEF) makes use of the Life Cycle Management (LCM) process to build up systems capability in the Singapore Armed Forces (SAF). The LCM is a project and systems engineering management process that governs systems life cycles. It consists of four major phases and a transition period: front-end planning, acquisition management/ systems development, transition to Operations & Support (O&S), O&S and systems retirement.

One of the advantages of using LCM is that it minimises the total cost of ownership (TCO) of the system while still allowing it to meet the mission objectives. The TCO of a system comprises the sum of all financial resources required for its acquisition, development, ownership, operation and disposal. The major cost components of the TCO are shown in Figure 1. The highlighted cost boxes are the subjects in this article's discussion.

Among its other functions, DSTA is responsible for the acquisition and management of Command, Control and Communications (C3) systems for the SAF. The DSTA project management team (PMT) has to estimate the TCO of all new systems during the front-end planning phase.

Once the set of requirements has been determined, the PMT estimates the cost of the system's hardware and software through market surveys. If the project requires development efforts, the cost variation risk can be extended to the contractor by specifying the deliverables that are tagged to milestones. The cost of DSTA engineering and management services rendered can also be estimated based on the scale and complexity of the project.

However, it is difficult to estimate the Integrated Logistics Support (ILS) cost and the Annual Recurrent Expenditure (ARE) in a project. Common ways of budgeting include rule-of-thumb percentage figures, or an analysis of initial cost breakdown. The former does not explain the cost drivers, while the latter does not usually take into account the contextual environment that affects actual expenditure.

With a better understanding of the fundamental factors affecting ILS costs and ARE, it is possible to provide clearer and more

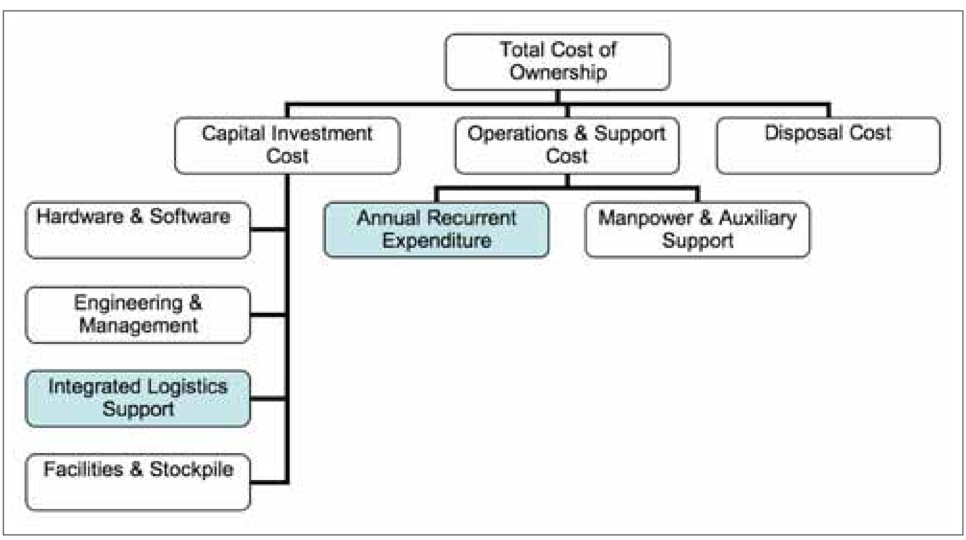

Figure 1. Major cost components for C3 systems

accurate cost estimates. This will in turn give a better TCO estimate of the project. This article presents a structured method of estimating ILS and ARE costs based on an analysis of the cost drivers and historical data.

COST ELEMENTS

ILS refers to a set of resources that ensures the effective and economical support of a system throughout its life cycle. As an integral part of the operational system, ILS is included as part of the capital investment cost. The major ILS elements for C3 systems include systems documentation, training, initial spares supply as well as support & test equipment (STE). These resources are usually acquired towards the end of the project.

Systems Documentation. Documentation includes operator manuals, technical manuals, software documents and all other information that are required for the operation and maintenance of the system.

Training. Different types of training are tailored for different target groups. Operator training provides the end users and systems administrators with knowledge on systems usage and configuration management. Maintenance training allows the technicians to perform corrective and preventive maintenance. In the SAF, the train-the-trainer concept is widely adopted. Instructors from military institutes develop internal training programmes based on the original equipment manufacturer's training syllabus. For complex systems, systems engineering training may also be conducted for military officers and DSTA engineers.

Initial Spares Supply. Spare parts are required to replace production parts that are in need of repair. For each system, the set of spares that is required is determined through computer simulation using inputs such as the training profile, component characteristics (e.g. mean time between failures) and repair capabilities (e.g. turnaround time).

Support & Test Equipment. STE are items that support the operation and maintenance of the system. They include physical tools as well as testing, handling and calibration equipment.

ARE refers to the annual recurrent expenditure that is needed for the maintenance of a system through its useful lifespan. For C3 systems, ARE can be attributed to five main cost factors:

DSTA Systems Management. DSTA is the systems manager for most C3 systems in the SAF. The systems managers are responsible for systems engineering support, maintenance contract management, systems serviceability and safety, configuration management, as well as maintenance policies and processes. They also manage systems upgrades and retirement.

Contractors' Maintenance Services. Depending on each system's maintenance support concept, contractors are engaged in preventive and corrective maintenance at different levels of maintenance support. At the depot level, contractors typically undertake repairs using shop replaceable units. Contractor services are also often used to supplement the SAF's manpower to perform C3 systems maintenance at the operator and technician levels.

Repair Material. Repair material refers to spare parts used to replace faulty parts in a system or sub-system. In cases where the system or sub-system cannot be repaired economically, repair material includes the purchase of suitable replacements.

Consumables. Consumables refer to expendable items (e.g. batteries) that are required for day-to-day systems operations.

Licenses and Subscriptions. Software licence fees are paid to the software vendors, while telecommunications subscription or usage fees are paid to telecommunications companies for network bandwidth services.

COST DRIVERS

To derive the ILS cost and ARE as percentages of the capital investment cost, several fundamental operational and system requirements are considered.

These requirements or cost drivers are in turn driven by socio-political and technology trends. They are independent of one another, and serve as inputs to the calculation of the ILS and ARE cost percentages.

Operational Cost Drivers

Five cost drivers are classified under the Operational Profile:

Training Location. Manpower costs for supporting exercises and training are part of the system's ARE. To supplement military personnel, civilian technicians and engineers are often employed in local exercises. Thus, costs to source civilian manpower must be considered.

Target Availability. The system's target availability will affect the volume of spares and manpower support that will be required for each system. For example, increasing the target availability from 90% to 99% will greatly increase the amount of maintenance spares and manpower support requirements.

Support Requirements. Manpower costs will increase if there are requirements for enhanced systems readiness support from contractors and DSTA personnel during the utilisation period. On-site maintenance support is always more expensive than off-site support (e.g. through phone).

Fleet Size. The bigger the fleet size of a technologically homogeneous system, the bigger the economy of scale to provide spares support and maintenance services. For example, a big fleet of military radios requires less maintenance cost (relative to the total investment cost of the radios) than a customised monitoring system that supports a small and unique group of users.

Telecommunications Requirements. If a commercial communication network infrastructure is needed for systems operations, the expected annual telecommunications charges will need to be taken into account.

Systems Cost Drivers

Three cost drivers are classified under the Systems Profile:

Systems Complexity. In each C3 system, the number of software applications, hardware platforms and system interfaces will affect the quantities of spares and STE. The level of complexity is a qualitative judgement call that the PMT has to make.

Depot-Level Support. Most depot-level maintenance support services are outsourced to the industry. The availability of depot-level repair capability in the local industry will usually reduce repair costs as local manpower rates are generally lower than in many foreign Original Equipment Manufacturer companies. Moreover, local repair capability will also reduce the turnaround for equipment repairs. However, setting up local repair capability will increase the initial set-up cost.

Software Requirements. Some C3 systems require annual subscriptions to software licences that are embedded in the applications, or are necessary for the system to interoperate with other C3 systems.

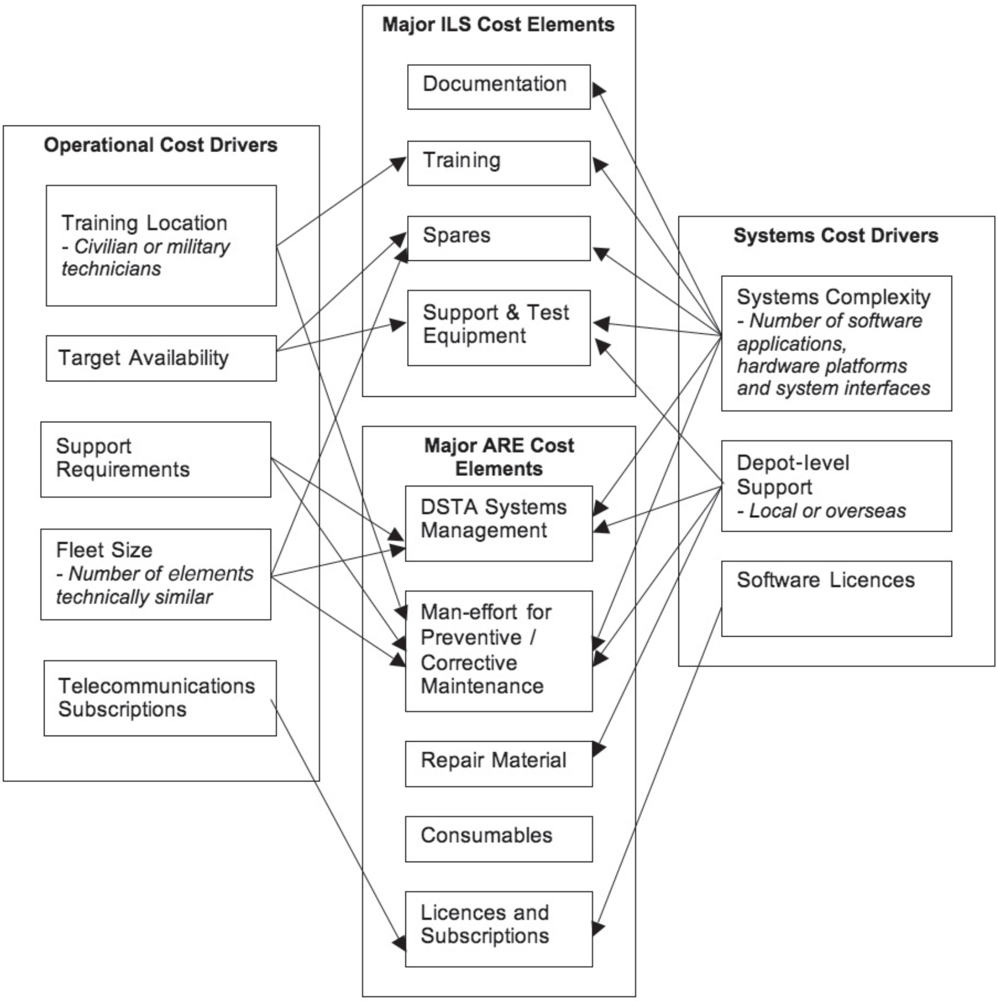

Figure 2. Relationship between the cost drivers and the cost elements

Figure 2 shows the relationship of these cost drivers to ILS and ARE cost elements. Each arrow indicates that the cost driver contributes to the respective cost elements.

Other Cost Drivers

Several other factors were thought to affect the percentages of ILS and ARE costs for each system. However, careful observation showed that some of these factors are attributable to the fundamental cost drivers discussed earlier. On the other hand, data analysis demonstrated a weak correlation between the rest of these factors to the cost percentages.

Capital Budget. There is a general observation that the larger the size of capital investment, the smaller the percentage of ARE. However, this can be attributed to the fact that expensive projects usually have large fleet sizes.

Maintenance Support Concept. In general, fixed-cost comprehensive maintenance contracts cost more than those which calculate charges based on the number of maintenance activities. However, the choice between these contract models depends on availability requirement and systems complexity.

Utilisation Hours. The frequency and duration that the system is in use may contribute to the cost of maintenance services, consumables, repair material and telecommunications subscription services. However, empirical data analysis suggests that their impact on the ILS and ARE cost percentages is not as significant as other cost drivers.

Training Environment. It is likely that factors such as operating the system in a mobile or static environment can affect the system's reliability and supportability. The number of different sites or platforms also affects maintenance support. However, empirical data suggests that the number of sites and platforms has little impact on ILS and ARE cost percentages.

Equipment Type. Whether the system is made up of military specification or commercial grade equipment, acquired off-the-shelf, or involve developmental efforts, the ILS and ARE cost percentages are not significantly affected.

PREDICTION METHODOLOGY

Project Scoring

A five-point scale is used to quantify the score of each project in each cost driver category. The score definitions for each of the cost drivers, shown in Table 1, are determined by observations on the operational and systems profiles in new and existing C3 systems. The definitions represent a good score spread among these systems.

As shown in Table 1, the cost percentages for telecommunications subscriptions and software licenses can be determined in a direct manner given the expected annual system usage, and hence they are simply added to the formulae (see section under ARE Cost Percentage Estimates).

Multi-Attribute Function

In formulating each of the ILS and ARE percentage costs, a multi-attribute function is

Cost Drivers	Score:	1	2	3	4	5
Operational Profile						
X1: Training Location		Overseas	80-20%	50-50%	20-80%	Local
X2: Target Availability		90%	95%	99%	99.5%	99.9%
X3: Support Requirements		Nil	Phone support	4hrs on-site	2hrs on-site	Stationed on-site
X4: Fleet Size (units)		>1,000	>100	>10	2-10	1
X5: Telecom Requirements		Estimated percentage of capital investment cost				
Systems Profile						
Y1: System Complexity		Simple	Slight	Moderate	Complex	Highly complex
Y2: D-Level Support		Local	80-20%	50-50%	20-80%	Overseas
Y3: Software Requirements		Estimated percentage of capital investment cost				

Table 1. Score of each cost driver

used to consider the relevant cost drivers as inputs. Since the cost drivers are independent of one another, an additive function is used. An exponential factor is needed for each of the cost drivers because the cost may not have a linear relationship with the scoring scale (as in Table 1). To simplify the function for users, it is defined in the following form:

$$Z = \sum_{i=1}^{m} \alpha_i X_i^{\beta_i} \qquad [1]$$

where Z is the objective function (i.e. ILS or ARE cost percentage);
m is the number of relevant cost drivers;
X is a cost driver;
α is a cost driver coefficient;
β is a cost driver exponential factor.

Model Fitting

In the above model, the coefficients and exponential factors for each of the cost drivers need to be determined. Due to the large number of unknowns and limited historical data available, unique optimum solutions for the coefficients and exponential factors could not be derived via simple regression analysis. Instead, the approach first derives the exponential factors based on management experience and the scoring scale in Table 1. For example, to determine the exponent β_2 for *X2* (target availability), simulations have shown that increasing the availability from 90% to 99% will require approximately five times more spares, and hence an exponential factor of 1.5 is deemed suitable.

Subsequently, the cost driver coefficients α_i are estimated by fitting the model and its derived exponential factors with historical data in existing C3 systems. This is done by minimising the root-mean-square-error (RMSE) in formula [2] between the model-estimated values and the historical data values using the Nonnegative Least-squares solver in Matlab. This solver employed a least-squares optimisation algorithm as described by Lawson and Hanson. In using this solver, it is assumed that α_i is non-negative, which is logical since the cost drivers can only contribute positively to the ILS and ARE costs.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - \hat{P}_i\right)^2}{n}} \qquad [2]$$

where n is the number of data points;
P is the actual cost percentage (ILS or ARE);
$\hat{P}$ is the estimate of the cost percentage using the model.

COST ESTIMATES

Using the model fitting technique described earlier, the ILS and ARE percentages, henceforth referred to as *Z1* and *Z2* respectively, are optimised separately for systems of the Army, Navy, Air Force and Joint Services. It should be noted that Navy and Air systems refer only to base area C3 systems, and not systems on naval or air platforms. They are combined as they share similar systems and operational profiles.

ILS Cost Percentage Estimates

The ILS cost of a C3 project as a percentage of the total capital investment cost is correlated to training location *(X1)*, target availability *(X2)*, fleet size *(X4)*, systems complexity *(Y1)* and depot-level support *(Y2)*, as illustrated in Figure 2. The ILS cost is part of the capital investment cost and its percentage *Z1* is estimated as:

$$Z1_{Army} = 6.07 \times X2^{1.5} + 0.97 \times X4$$

$$Z1_{Navy\,\&\,Air\,Force} = 0.64 \times X2^{1.5} + 2.7 \times Y2$$

$$Z1_{Joint} = 0.13 \times X1 + 0.56 \times X2^{1.5} + Y1^{0.5}$$

These estimates give a range of ILS costs from 7.0% to 10.9% for existing Army systems, 4.5% to 12.6% for Navy and Air systems, and 2.6% to 5.3% for Joint systems. The RMSE based on these formulae are 5.23%, 3.02% and 1.06% respectively.

ARE Cost Percentage Estimates

The ARE of a C3 project as a percentage of the total capital investment cost is correlated to all factors listed in Table 1 except target availability *(X2)*. The ARE is not part of the capital investment cost. Using the same model fitting technique, the ARE cost percentage *Z2* is estimated as:

$$Z2_{Army} = 0.57 \times X4^{1.5} + X5 + 1.46 \times Y2 + Y3$$
$$Z2_{Navy\,\&\,Air\,Force} = 1.22 \times X1 + X5 + Y3$$
$$Z2_{Joint} = 0.31 \times X3^{2.0} + 0.74 \times X4^{1.5} + X5 + 0.38 \times Y1^{2.0} + Y3$$

These estimates give a range of ARE from 2.0% to 11.9% for existing Army systems, 1.2% to 6.3% for Navy and Air systems, and 6.8% to 13.3% for Joint systems. The RMSE are 2.92%, 2.73% and 4% respectively. The ARE estimation is based on the year when the project moves into the O&S phase. The cost for subsequent years will be subjected to annual price escalations.

CONCLUSION

This article provides a general analysis of how the ILS and ARE cost percentages are dependent on the identified cost drivers, and how these percentages can be estimated using the derived formulae. The article also provides a systemic approach for front-end project planners to budget for the costs associated with the later phases in the project.

It has to be emphasised that the model only provides an estimate of the cost percentages, since the error margin can be improved when more data points (i.e. more projects) become available in the future. Experienced systems managers should be consulted to identify other possible cost drivers. Refining the coefficients and exponential factors in the formulae should be a continual effort.

After successful implementation and validation, the model can be extended to other types of systems in the SAF. However, since the cost drivers and major cost elements in the other systems may differ, the model should be fine-tuned accordingly.

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BIOGRAPHY

Wong Choon Bong is a Principal Engineer and Branch Head (Systems Management) and oversees the maintenance of communications systems in the Army. A communications engineer by training, Choon Bong has experience in project management, software development and systems integration. He also served in the Army Chief Information Officer Office, where he was responsible for the IT Infrastructure portfolio. Choon Bong received his Bachelor degree in Electrical Engineering from the National University of Singapore (NUS) under the Defence Technology Training Award in 1998. He obtained a Master of Electrical and Computer Engineering degree under the DSTA Postgraduate Scholarship from Cornell University, USA in 2004.

Tay Yeow Koon is Deputy Director (Systems Management – Operations & Support). He manages all Operations & Support (O&S) matters and oversees the systems management of Command, Control, Computing Intelligence systems of the Ministry of Defence and Joint Services. Yeow Koon has extensive experience in the Command, Control, Communications, Computers and Information Technology domain involving diverse users from the Singapore Armed Forces and homefront security agencies such as the Singapore Police Force and Singapore Civil Defence Force. Yeow Koon obtained a Bachelor degree in Computer Science from NUS and completed the General Management Programme at Harvard Business School in 2009.

Ma Jiamin is an Engineer (Systems Management). She is currently involved in Integrated Logistics Services as well as O&S engineering work for communications systems in the Army. She has also worked on several aspects of the physical layer of communications systems during her attachment to DSO National Laboratories. Under the DSTA Undergraduate Scholarship, Jiamin received a Master of Electrical and Electronics Engineering degree from Imperial College London, UK in 2008.