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**SUPPORT MANAGEMENT FOR CANADIAN FORCES
DEFENCE EQUIPMENT PROGRAMS:
TOWARD DEVELOPING DESIGN CRITERIA FOR A
LOGISTICS SUPPORT MONITORING SYSTEM**

by

Peter Ludorf, B.Sc. (Applied)

*A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Management Studies*

School of Business

Carleton University

Ottawa, Ontario

November 1, 1990

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LOGISTICS SUPPORT MONITORING SYSTEM"

submitted by Peter Ludorf, B.Sc.(Applied)
in partial fulfilment of the requirements for
the degree of Master of Management Studies.

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ABSTRACT

This thesis deals with the general concepts underlying Integrated Logistics Support (ILS), an approach to support management recently adopted by the Canadian Forces to ensure that there is an integrated effort for the consideration of logistics elements in the support of weapon systems or other defence equipment throughout their life cycle.

An integral part of ILS is the Logistics Support Analysis (LSA) process. LSA includes the analytical procedures that are performed in the initial phases of a new weapon system/equipment life cycle to identify and define those ILS elements necessary for the optimal mix of logistics support that can be expected for the remainder of the life cycle. The results of LSA are documented in the LSA Record (LSAR), a database containing the analytically derived baseline predictions of logistics support requirements.

Logistics Support Monitoring (LSM) is envisaged as a system that would evaluate the adequacy of the logistics support provided (during the in-service phase) compared to baselines such as management goals, norms, other previous usage data and/or the LSAR prediction. LSM would evaluate ILS performance. By using field reported supply, operational and maintenance data reflecting the actual usage of the defence equipment, LSM would highlight where intelligent management intervention and/or changes in the logistics support package originally identified by the LSA process are required.

Before an LSM system can be developed, however, certain broad design considerations must be taken into account. These include management involvement, characteristics of the input data, output requirements of the users and selecting appropriate forecasting methods.

In order to demonstrate much of the conceptual framework of LSM, a preliminary representative computer-based prototype is presented. The prototype exhibits how LSM alerts logistics staff to potential problem trends in the defence equipment's maintenance performance. Having this indication would allow the staff to be proactive rather than having them react to problems that have already occurred.

The LSM system will be useful to project managers, Weapon System Managers, Life Cycle Materiel Managers and other middle and senior management personnel of the Department of National Defence. The principles, however, are equally applicable to the commercial transportation sector and equipment intensive industry.

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I am especially indebted to Majors André Arès and Daniel Messier, my co-members of the NDHQ LSM Project team who have been instrumental in introducing this Army officer to what had heretofore been largely an Air Force area of interest. Their critiques of prior drafts of this thesis, laborious explanation of background concepts, and computer programming skills have made this thesis possible. Other fellow officers whom I have consulted have shown interest and enthusiasm for the project. Their cooperation and encouragement has also been greatly appreciated.

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LIST OF ABBREVIATIONS

ADAM - Automated Data for Aerospace Maintenance

AMMIS - Aircraft Maintenance Management Information System

ASR - Department of National Defence Aircraft Serviceability Review (1986)

AUSR - Aircraft Utilization Statistical Report

CDRL - Contract Data Requirement List

CF - Canadian Forces

CF5 - CANADAIR version of Northrop F5 Freedom Fighter jet (officially, CF116)

CF18 - Canadian version of McDonnell-Douglas F 18 Hornet jet aircraft

CFSS - Canadian Forces Supply System (specifically its database)

DAS Eng - Directorate of Aerospace Support Engineering of NDHQ

D Log A - Directorate of Logistics Analysis of NDHQ

DND - Department of National Defence (Canada)

DoD - Department of Defense (U.S.)

EMMIS - Electronics Maintenance Management Information System

ESM - Equipment System Management

FH - LSM Parameter Flying Hours

FMECA - Failure Modes, Effects and Criticality Analysis

ILS - Integrated Logistics Support

LCC - Life Cycle Cost Analysis

LCMM - Life Cycle Materiel Manager

LORA - Level of Repair Analysis

ABBREVIATIONS (Continued)

LSA - Logistics Support Analysis

LSAR - Logistics Support Analysis Record

LSM - Logistics Support Monitoring

MASP - Maintenance and Support Program Study

MFR - Monthly Flying Rate

MIL-STD - U.S. Department of Defense published Military Standard

MMIS - Maintenance Management Information System

MTA - Maintenance Task Analysis

MTBF - Mean Time Between Failures

MTBR - Mean Time Between Replacements

MTTR - Mean Time To Repair

NDHQ - National Defence Headquarters (Ottawa)

PHST - Packaging, Handling, Storage and Transportation

RCM - Reliability Centered Maintenance

RAM - Reliability, Availability and Maintainability

R and M - Reliability and Maintainability

TOT_MHRS - LSM Parameter Total Maintenance Man Hours

USAF - United States Air Force

1. INTRODUCTION

1.1 General

Logistics Support Monitoring (LSM) is a subject that deals with Integrated Logistics Support (ILS). ILS is a complex and wide-ranging concept which has many specialties associated with it both in the military and in (largely defence related) industry. This paper does not presume to make the reader an ILS "expert". Rather, a brief description of ILS and related topics is given to provide some familiarization with the concept and to lay the groundwork for understanding how an LSM system will be an important tool in evaluating the effectiveness of an ILS program for a Canadian Forces military weapon system or a defence support system (consisting of other equipments) and thereby assist in the determination of where changes to the logistics support package are required. For the purposes of this study, weapon systems and defence support equipment systems will collectively be referred to as defence systems.

Before beginning any discussion of ILS, it is first necessary to understand what the term "logistics" means in the context of ILS. Most people associate logistics with supply related activity, i.e. sparing, initial provisioning, warehousing, transportation, etc. The logistics of ILS, however, encompasses these and a host of other activities related to the support of defence systems. The Society of Logistics Engineers (SOLE) offers a definition of logistics which is seen to best define the activities carried out by the Canadian Department of National Defence: "Logistics is the art and science of management, engineering and technical activities concerned with requirements, design,

and supplying and maintaining resources to support objectives, plans and operations."¹

In order to improve the cost effectiveness of the acquisition and in-service phases of defence systems programs, National Defence Headquarters (NDHQ) in Ottawa promulgated Policy Directive P3/87 in May 1987. It directed that the ILS concept would henceforth be adopted for all Major Crown Projects (defined as being those costing in excess of \$100 million) for Canadian Forces defence systems. The ILS concept provides for consideration of the logistics support needed to achieve the specified and planned level of systems effectiveness at the least life cycle cost for defence systems by relating and tracking all the various elements of support. ILS can otherwise be defined as a systematic, structured and rational way of achieving the proper balance between supportability and cost.

ILS has its roots in US military acquisition programs. The "design for maintenance" ethic of World War II vintage defence systems simply required a maintenance organization which had the necessary tools, personnel, training, adequate spares and sufficient documentation (technical manuals) to get the job done. As the complexity of defence systems increased, maintenance alone was becoming a greater and greater major consumer of resources. Reliability and maintainability (R and M) considerations of the 1950s and 1960s were, therefore, developed in order to contain those maintenance costs. The greater sophistication of weapon systems and other defence equipment saw designers concerning themselves not only with the system's ability to perform the required operational task reliably, but also with its ability to be maintained.

¹ Major V. Robertson, Ottawa Chapter President SOLE, 12 August 1988.

R and M had, and continues to have, a profound effect on the design and development of defence systems. However, in the late 1960s the U.S. Department of Defense identified the need for a more structured approach to planning, developing, and managing the entire spectrum of logistics support considerations for these programs. The US military was no longer willing to buy a defence system and automatically accept whatever logistics support costs showed up downstream. ILS thus evolved at that time to include not only a structured maintenance planning process and R and M, but also the many other elements of support such as training, documentation, spare parts, facilities and computer equipment, to name a few.

The development of ILS is, therefore, seen to stem from the dual objectives of improving operational availability (and therefore operational effectiveness) through better support, while at the same time reducing the costs of support over the life cycle of the defence system. ILS is a composite of the management and analysis actions necessary to ensure the effective and economical support of a defence system at all levels of maintenance for its programmed life cycle.

The ILS concept is a unified and iterative approach to the managerial and technical activities necessary to:

- a. cause support considerations to influence both requirements and design of a system;
- b. define support requirements which are optimally related to the design and to each other;
- c. acquire the required support; and

- d. provide the required support over the life of the equipment at the lowest possible cost.

With this discipline, the design of the defence system is influenced by logistics support considerations such as are shown in Figure 1.² The engineering design efforts and the logistics support are fully integrated under ILS with the ultimate objective being a more cost effective support program.

Figure 1 Integrated Logistics Support Elements

ILS activities begin in the conception phase of a defence system project and continue throughout the in-service life of the system. As the life cycle progresses, support plans are adjusted through the use of Logistics Support Analysis (LSA) techniques. Figure 2 shows the objectives of LSA by life cycle phase.³

LSA constitutes the application of selected quantitative methods to:

- a. aid in the initial determination and establishment of logistics criteria as an input to system design;
- b. aid in the evaluation of various design alternatives;

² From DND ILS course, 1988.

³ From DoD ILS Guide, 1986.

- c. aid in the identification and provisioning of logistic support elements; and
- d. aid in the final assessment of the support capability during consumer use.⁴

In other words, LSA is a series of design analysis **Figure 2 Logistics Support Analysis Process Objective by Program Phase**

tools employed primarily in the early phases of system development to determine the optimal mix of logistics support. It can continue, however, throughout the remainder of the equipment life cycle so as to update that previously determined logistics support. It often includes maintenance task analyses, life cycle cost analysis and logistics modelling to forecast the support requirements for the system. Much of the data is analytically estimated, borrowed from other similar projects or is otherwise derived. The aim of the progressive planning adjustment is to maintain sound engineering and logistics tradeoffs during the service life of the system.

An output of the ILS/LSA process is the Logistics Support Analysis Record (LSAR),

⁴ NDHQ Policy Directive P3/87, May 1987.

a contract deliverable that can be purchased from the contractor for each major defence system program. It is the identification of and justification for logistics support resources and contains a database of the manufacturer's specifications, expected performance characteristics and anticipated maintenance levels. It can also include expected maintenance personnel quantities and skill-level requirements, test and support equipment, and, of course, a good estimate of spare and repair part types.

The Canadian Forces experience with the LSAR began with the CF-18 fighter aircraft program in the early 1980s. The option for purchasing an LSAR deliverable product is now a standard feature in contracts for new defence systems programs. The massive (and very expensive) LSAR database is used extensively in the project development stage of the life cycle by providing a baseline of projected logistics support requirements.

After the defence system has been acquired and fielded, a baseline could similarly be used during the deployment phase of the life cycle in order to evaluate how the logistics support of the system is performing relative to set management goals and thus indicate where logistics support changes are required. The management goals could consist of baseline values such as long term established norms, previous usage data or values identified in the LSAR.

This comparison of actual to baseline values, however, is not being done by automated means at the present time. Manual comparisons and the search for significant trends in the reams of supply and maintenance database printouts are simply too slow, inaccurate and inefficient. Thus, the main objective of this thesis is to study the design considerations that are necessary to develop a computerized method which would compare

field data with baseline values and which would forecast how trends in the field data are developing based on historical performance. This method is called LSM.

Field commanders in all arms of the Canadian Forces are tasked with being ready to carry out their missions, be they peacetime training, responding to an emergency, or war, with the manpower, weapon systems and defence support equipment they hold on their units' establishments. Readiness is a function of quality, quantity and preparedness of military personnel and equipment. Commanders require their defence systems to be optimally maintained at all times in order to be prepared to accomplish their missions and to avoid unnecessarily jeopardizing the lives of their personnel or members of the civilian population. They must make the most efficient use of their resources. It is the mandate of the support staff to ensure that the unit has those resources of trained and ready manpower, appropriate equipment and systems, adequate spare parts, suitable provision for replenishment, and the ability to repair a breakdown of those defence systems if and when they occur.

Keeping their units fully operational and ready, of course, is no easy task. For example, a typical complaint from field commanders is that excessive delays are experienced in acquiring spare parts to repair their equipment. Additionally, weapon systems or other defence support equipment that are sent for repair to more sophisticated maintenance facilities for comprehensive or complex repairs or overhauls are often delayed for a variety of reasons, one of which, again, is a lack of spares. One reason for this could be that the planning staff may have inaccurately assessed the quantities of spares required. This may have occurred either because consumption rates were

significantly different from those expected for new equipment, or because trends in increasing consumption of repair parts were not fully appreciated for mature defence systems. For instance, in the first case, manufacturers' LSAR predictions regarding the reliability of new systems, equipment or components may have been significantly in error from that actually experienced in the field, while in the second case, continuing heavy use of the older generation equipment may be resulting in more components becoming worn out. Replacement parts should have been stockpiled in anticipation of such a trend. Operational efficiency is not only the commander's concern, but also the support staff's.

LSM is seen as an important method to deal with this type of problem (spare parts provisioning) within the ILS concept. Similar problems that could be addressed range from the adequacy of the training of technicians to the suitability of facilities required to effect repairs.

LSM is conceptualized as a computerized system in which historical field observed logistics support performance data pertaining to a defence system (available from various databases) forms the basis of a forecast of future performance. The past field-reported time series supply and/or operational and maintenance data will have been collated in terms of performance measurement parameters. The forecast is then compared to the LSAR, the management goal or another baseline value. The LSM system would generate an alert if a significant difference is detected between actual or forecasted performance and the baseline value. The "significant difference" would be gauged in terms of threshold values (alert levels) which are relative to the baseline and which would have been programmed into the system according to the requirements of the analyst. The

analyst (usually a maintenance manager concerned with a particular defence system) determines the values the alert levels are to have. For example, the maintenance manager could define the alert level threshold as being, say, 95% of the long term historical values (the baseline in this case). In other words, only the actual performance value or its forecast that exceed the baseline by 5% or more would automatically trigger the alert. The system should be able to provide a trend analysis as requested by maintenance management staff on any preprogrammed performance parameter for any equipment on which historical logistics data has been gathered. The alert, on the other hand, would be generated only when the LSM system, periodically (such as on a monthly basis) monitoring the predefined parameters, automatically detects a worrisome trend developing in one or more of those parameters. The trend analysis and alerts would allow management to anticipate where a potential deterioration of logistics support may be developing and, therefore, take preemptive corrective action as opposed to reacting in a "fire-fighting" role to a problem that has already occurred.

An additional feature of LSM would be that if an LSAR or other chosen baseline value is found to be consistently and significantly inaccurate, LSM could alert staff to the requirement to have that value changed to one more representative of true performance levels. This can be done by having management assign more realistic values to the baseline or having the contractor/supplier change the LSAR value. The former case would be the most common. In the latter case, changing an LSAR value would be expected to be very rare. Instead, a closer dialogue would probably result between the contractor/supplier and the customer to determine the cause of the major disparity.

LSM is, therefore, seen to have two functions. The first is to evaluate how logistics support is performing relative to expectation, and the second is to forecast how that logistics support can be expected to perform based on past performance if no changes are made to the mission, the maintenance program or the environment. In both functions, management gains valuable insights into the vital area of logistics support.

Before an LSM system as described above can be fielded, however, a number of characteristics concerning its design must be considered. Therefore, this study is intended first to describe the basic principles of ILS necessary to appreciate the significance of an LSM system, and then to discuss the LSM design criteria. An initial prototype LSM forecasting model is described to demonstrate the concept of evaluating logistics support (specifically, maintenance) performance and its forecast relative to a given standard. It must be emphasized, even at this early juncture, that the prototype (or any model, for that matter) is not the thrust of the study, rather, the importance lies in the key management considerations that are necessary for the development of a functional LSM system.

The thesis is organized in seven parts. In the following part 2, some of the problem issues that relate to ILS/LSA and which apply to LSM are discussed and the problem statement is given. Next, the relevant literature concerning the evolution and principles of ILS/LSA and the preliminary studies that lead to LSM is examined. Part 4 discusses the management principles germane to LSM. Part 5 describes the design considerations for developing an LSM system and part 6 presents a preliminary computer-based LSM forecasting prototype. Finally, in part 7 the implications concerning the use of, and future directions for, an LSM system are discussed.

2. PROBLEM DEFINITION

2.1 Background

The recently retired Chief of Materiel Services and Logistics Operations of the Canadian Forces, Major-General George MacFarlane, was, in his military career, and remains today, a strong advocate of increased management efficiency and exploitation of technology. He has noted that in Canada, as in most other western nations, defence budgets are becoming more limited and are coming under closer scrutiny by governments and various interest groups. With the recent phenomena of "peace breaking out all over", there is even greater pressure to reduce defence budgets, and capitalize on the "peace dividend". Defence planning must, therefore, be more thorough, efficient and must be seen to control costs not only during the acquisition phase of major defence system projects, but also during the in-service phase, where support costs usually total several times the acquisition costs. In order to achieve fiscal control yet still increase operational efficiency a wide range of initiatives have recently been taken by the Canadian Forces to exploit technology and to improve defence systems management for existing systems and project management approaches for those being planned. Among these initiatives are policies implementing ILS, Equipment System Management (ESM) and Reliability Centered Maintenance (RCM).

He also observed that one difficulty that lingers in defence system program management is finding an acceptable trade-off between funding the purchase of the number of primary fighting vehicles initially identified as being required, and funding the

logistics support package required throughout the life cycle of that equipment. Every reduction from what was originally seen as the optimally designed project, either in numbers of primary fighting vehicles or in their support systems, implies a significant penalty in systems/operational effectiveness. The operationally effective balance (trade-off) between quantities of equipment purchased and life cycle support costs can be estimated by ILS and LSA analyses in the project definition and acquisition phases of the defence system life cycle. In order to remain within budget, those estimated logistics support costs cannot vary greatly from those actually experienced. In other words, continual monitoring of logistics support is required to ensure that there are no expensive surprises.

General MacFarlane has confirmed that the Canadian Forces are now committed to the ILS concept for support program management optimization. Reliability analysis, life cycle cost analysis, cost-benefit analysis and other LSA functions are now routinely used to justify to senior management the need for, and the economics of, modifications to defence systems. The outputs of LSA, comprising computed workloads at each level of maintenance, estimate the manpower and degree of skill required to each of those levels and, therefore, what specialized training, tools, test equipment and technical documentation are required to perform each job. The outputs also estimate the level of spare parts required at each level of maintenance facility to satisfy the anticipated workload based upon the length of the supply pipeline and the efficiency with which spares can be delivered promptly from warehouse to shop. Management can only determine how accurate those estimates were during the in-service phase by monitoring

the actual performance using proper evaluation tools. Monitoring performance can, therefore, help to identify if and where changes to management set goals are required.

In his experience, the General has found that a universal complaint common to every Canadian Forces procurement project is the seeming inability of prime contractors to obtain the technical data required to perform the LSA, to compile the LSAR, to make ILS decisions, to prepare and execute training programs for operators and maintenance technicians and to establish the required software support capability. In order to address these issues and their associated spiralling acquisition and in-service support costs, innovative project management approaches must be found which exploit the advantages of new technology.

Some encouraging inroads are currently being made by the Canadian Forces to address these issues. Key to the improvement in project management techniques is a series of enhancements in the management information systems field that have recently been introduced. These should soon yield a greatly improved capability to track the systems' effectiveness being realized in-service by facilitating full use of data now being collected but which is only being partially or inefficiently used today. The development of a second generation Project Management Administrative Support System and of a complementary Life Cycle Materiel Management System has been started. The latter system is planned to use data from the field and from contractors, furnished by improved and more user-friendly maintenance management information systems (MMISs). All of these systems are intended to interface with a new upgraded Canadian Forces Supply System (CFSS), the database management system that controls all supply functions for

the CF. The integration of all these systems and the production of meaningful information useful to both middle and senior levels of management in decision making, are seen by him to pose daunting challenges. One example General MacFarlane gives is that the eventual usage of the reliability and maintainability data that are collected by the MMISs is limited only by the imagination, experience and workload of the maintenance managers. They should be given the tools to allow them to deal with problems proactively.⁵

LSM, the subject of this thesis, is one application that is being studied under the Life Cycle Materiel Management System to make more meaningful use of the available data. The effectiveness of the logistics support of defence systems would be tracked by using the above noted MMISs to evaluate the ILS program relative to the contractors' expected values (LSAR) or other management accepted baselines. Additionally, LSM will be designed to look for trends that may indicate deteriorating logistics support in order to alert management to these warning signals.

2.2 Integrated Logistics Support

Appendix A identifies the principal components of ILS and the major analyses and tasks constituting LSA. It is not intended to go into great depth on these topics in this thesis, but rather to discuss ILS issues that relate to LSM.

ILS has emerged from lessons learned in the project management of major defence

⁵ Keynote address to the 1988 Annual I.E.E.E. Symposium on Reliability and Maintainability, Los Angeles, 12 January, 1988.

system projects in the U.S. during the 1960s and 1970s. It was determined that there was a need for more structured approaches to planning, developing and managing logistics support programs. That is, it was concluded that the logistics support for any major defence system is equally, if not more, important than the operational performance of the defence system alone. The fundamental objectives of ILS are to improve operational availability (a function of readiness) through better support and to reduce the costs of that support over the life of the defence system. ILS is considered to be a systematic and structured way of achieving the proper balance between supportability and cost. This is generally done by trading off resources between the two. ILS has a formal structure which forces management to consider many relevant factors prior to decision making. For example, there exists a requirement for formal documentation in an ILS program to ensure that there is an audit trail for all important decisions. The Canadian Forces has recently adopted the principles of the U.S. ILS system as the cornerstone for its own ILS system.

ILS deals with all aspects of logistics support, not just the traditional important function of supply. Other aspects of support such as training, technical data, test equipment, manning, maintenance policy, facilities and computer resources which were once dealt with separately are now considered jointly under the umbrella of ILS. The integration of planning, developing and managing all of the functions and elements of the support package is what ILS is all about. A proper ILS program helps to ensure that the right spares, the right test equipment, the right technical data etc. are at the right place at the right time to support the primary system, all at the least cost over the life of the

system.

The design of defence systems must include provision for their supportability. Design engineers must work closely with ILS engineers to ensure that supportability criteria relate to reliability (minimize the number of failures) and maintainability (maximize the ease of repair). The design of the support system (all of the support elements) for the primary system must also be considered. The principal tool for performing this function is the Logistics Support Analysis (LSA). LSA encompasses the activities and tasks associated with defining logistics support requirements and the support resources required to fulfil those requirements. Appendix A briefly describes some of the major functions integral to LSA such as Reliability Centered Maintenance, Level of Repair Analysis, Failure Modes Effects and Criticality Analysis, Maintenance Task Analysis and many other trade-off analyses, all aimed at defining the best and most economical support system for new equipment. The significance here is that LSA initially defines the logistics support required. Continuing to define the optimal logistics support as the system matures is a dynamic process. The accuracy of the initial LSA predictions should be evaluated in relation to actual performance and changes to the support program should subsequently be made as required when deficiencies have been identified.

Also, since ILS is still quite new in the Canadian Forces, there are relatively few trained and experienced ILS managers. The result is that often both the customer (DND) and the contractor are managing an ILS program with little or no experience. Checks and balances are necessary to ensure that the ILS program stays on track.

2.3 Data Management

The various analyses that are performed during an ILS program and the many functions that are integral to ILS itself result in very large amounts of data. Data management is one area that is prerequisite to having an effective ILS program and is one that has been most difficult to resolve in past defence system programs.⁶ In order to address this problem, the results of LSA are held in a structured (as per MIL-STD-1388-2A) database called the LSA Record (LSAR) which contains the contractor's expected performance characteristics of the defence system in a standard data format. The management of other ILS data, however, such as observed performance, retrofit requirements, change in mission or training, has been fragmented. Organizations responsible for different phases of the life cycle operate with considerable autonomy and other organizations responsible for different functions show little concern regarding functional, and hence, data interfaces. A more coordinated approach is required. Data is a resource that must be managed, therefore, policy, procedures, and systems must be established.

Data reporting is an essential aspect of maintenance and other ILS support tasks. To minimize the effort required to prepare and submit data, the process should be automated as much as possible. Ideally, data capture should be an unobtrusive byproduct of the task. The effort required to provide data should at least be balanced by the value of the services received from the system.

⁶ Final Report to Treasury Board on the CP-140 Aurora Acquisition Program, January 1982. This was the first trial at using the ILS concept in DND and identified data management as one area where improvements were required.

The five Canadian Forces MMISs (for army, navy, air force, communications and electronics and test equipment) and the Canadian Forces Supply System hold observed field data on the actual performance of defence systems and equipment. Each of these MMISs has been designed to address the specific requirements of the element it serves. For example, the army MMIS, known as LOMMIS, is principally designed to manage the workshop environment and to account for manpower utilization in maintaining a defence system such as a tank. Communications and electronics staff, using EMMIS, on the other hand, are mainly concerned with the performance of the defence system, such as a radar.

These information systems contain the historical maintenance data bases that are the principal tools with which the Life Cycle Materiel Managers (LCMMs) determine the day-to-day logistics support performance of the equipment for which they are responsible. In order to allow these LCMMs to most effectively use the data, there exists the requirement to have that data properly managed. All users and providers of the data must be coordinated and be in agreement as to what should be reported and to what use it will be made, an objective of the various MMIS upgrade projects.

2.4 Life Cycle Materiel Management

There are several hundred civilian and military members of DND employed in LCMM duties. They are responsible for the logistics support of the various defence systems and equipment used by the Canadian Forces. Life Cycle Materiel Management is defined as: "the effective management of all activities required to acquire and support equipment or systems from the time of its initial conception to the time of its disposal from the

Canadian Forces"⁷. In order to fulfil this mandate, LCMMs must have timely, complete and accurate information available to them on their equipment. They must, therefore, of necessity be involved with the policy, direction and development of the system which provides them with the information to perform their management function. When they detect deteriorating performance, LCMMs investigate the cause(s) and order corrective action to be taken. The support system performance which they monitor includes the number of maintenance actions of specific kinds carried out on the equipment fleet (such as the total number of engine replacements for the Leopard family of tanks that occurred in a particular period, as opposed to investigating whether one specific tank had an engine replaced in that period), the number and types of spare parts that have been requisitioned from the supply organizations and the ability of technicians to carry out repairs promptly and correctly. LCMMs routinely compare reports of these performance indicators manually with baseline values that have been determined by long-term norms, have been set by senior management, are based on comparisons with other similar equipment, or have been extracted, again manually, from the LSAR. The problem is that, considering the huge amounts of data that must be sifted through, it is not uncommon for only the most obvious problems to come to light. Identifying a problem trend that may be developing by observing the historical data not only requires the skill of a knowledgeable and experienced LCMM, but also a considerable degree of serendipity.

As has been indicated above, some limited integration of the different information systems has been achieved by some LCMMs by manually cross-referencing the output

⁷ from CFP 113, *The Life Cycle Management System Manual*, Ottawa, 1987.

reports and mentally visualizing a trend. For example, by noting from a supply printout that there is an increased consumption of generic valve gaskets which his motors (and others) use, the LCMM for that family of motors might only then recall seeing a MMIS report which had indicated that an increasing and unexplained number of manhours were recently being expended in installing gaskets in a particular family of vehicles equipped with his motors. He would then estimate that if the trend continued, an unacceptable level of logistics support (acquiring and delivering the gaskets and the unexpected burden on the maintenance facilities which were actually performing the replacement task) would soon be expended relative to the amount he had budgeted for. This in turn could prompt him to begin to investigate the causes for these phenomena. It could be that a new supplier had recently been awarded the gasket supply contract and the only reason that deteriorating performance was being reported for his motors was because they ran hotter than others and the gasket was breaking down more frequently under the high heat than did the previous supplier's. In this example, the LCMM may not have acted having only one report, but by correlating the two reports and doing some investigating, he was able to solve the problem, presumably by changing the temperature specifications for the gaskets and replacing the faulty stock.

This type of laborious analysis, however, cannot be expected routinely due to the sheer volume of printouts that must be vetted on the literally hundreds of thousands maintenance significant items for defence systems. An automated means of comparing actual to expected ILS performance would, therefore, be a key productivity tool to allow LCMMs to more effectively perform their duties.

2.5 Problem Statement

It is not sufficient to implement the concepts of ILS. Management implies control, including determining what course of action to take when there is a difference between plans and reality. NDHQ studies have shown that regular monitoring of both maintenance and supply parameters to assess their individual or consolidated performance is essential to determine the reasons for unsatisfactory serviceability rates of some defence systems. The same studies have shown that most of the required data is already present in the maintenance and supply databases. However, they are not well integrated and meaningful information cannot be easily drawn out from them⁸. What is ultimately needed is a way of electronically integrating the relevant databases and drawing information out of them in an easy and user-friendly manner.

In the example cited above, an alert should automatically have been generated by an LSM system when it detected that a trend was developing in the Supply System's report of increased gasket consumption in conjunction with the MMIS report of increased gasket installations relative to the numbers of both planned. When the LCMM receives an alert, he would then start an investigation for the cause(s) such as ultimately determining that the new gaskets were more prone to high temperature breakdown. The integration of the databases and comparison of performance relative to management's baselines should take place in the computer, not in the LCMM's mind.

LSA, consisting of quantitative analyses on several logistics concerns such as life

⁸ Eyretechnics Co Ltd. *DND Aircraft Serviceability Review (Automated Aircraft Performance Monitoring) Phase 7 Report*, Ottawa, 1986.

cycle costing, logistics modelling, and maintenance analysis, generates large volumes of projected performance characteristics data of new defence systems. These data, stored in the LSAR database for that specific defence system, are currently used extensively in the program design, development and acquisition phases. They are not, however, widely used once the defence system is deployed in the field. In the past, some project and weapon system managers have been tempted to "unplug the computer" upon completion of the capital procurement phase of the project. They have viewed the millions of dollars spent on gathering the LSA data as an expense rather than as an investment. Many have thought that LSA is finished once the defence system and the initial logistics support package have been delivered.

Experience has shown, however, that the logistics planning effort is never finished; it continues throughout the entire life cycle of the defence system. Logistics support plans must be dynamic, not static. As new technology and system interfaces are introduced, plans must be adapted. What was once considered to be an optimal mix of logistics support needs to be constantly reassessed. It would seem appropriate to take the LSAR predicted value or other key baseline values for comparison to the observed logistics support provided and then determine whether changes are required in that support.

It should be noted that since an LSAR has only been purchased for relatively few recently acquired defence systems, primarily aircraft, other baseline values must be used for older defence systems for which no LSAR exists. Those baselines could consist of norms or averages established by long term observation of the equipment, management

directed goals or baseline values determined by some statistical calculation. Their significance in evaluating logistics support performance, however, is completely analogous to using the LSAR.

In summary, management (Weapon Systems Managers and Life Cycle Materiel Managers of Canadian Forces' defence systems) must have some means to measure the adequacy of the logistics support being provided relative to a predetermined baseline value (management goal). Manual performance of this function is time-consuming, manpower intensive, inefficient and imprecise. An automated performance monitoring capability is needed to allow these users to screen summarized operational, MMIS and CFSS data in order to identify logistics support problems before they have a negative impact on operations. Such a capability is envisioned with LSM.

Before a fully operational LSM system can be fielded, however, its cornerstone design considerations must be defined and addressed.

The research problem statement therefore is: What are the key design criteria necessary to developing an operational LSM system?

A number of design criteria for an LSM system are presented in this thesis. In order to exhibit the feasibility of such an LSM system, an initial prototype model which monitors the ILS element of maintenance is introduced.

Once a fully operational LSM system has been developed and fielded, it will greatly assist management to take the proactive posture that is largely an unachievable goal today.

3. LITERATURE REVIEW

This literature review has been prepared in a hierarchical manner in order to familiarize the reader with the building blocks leading up to LSM. There are many books and articles on maintenance and maintainability, most having a production and operations management perspective. There are also several recent articles concerning issues and specific applications of ILS and LSA. Performance monitoring of an ILS program, on the other hand, is not widely discussed. This review therefore takes the reader through the evolution of the ILS concept leading to the requirement for a monitoring system.

3.1 General

In the field of support management, the open literature on the subject of Integrated Logistics Support consists mainly of technical papers, case studies of specific applications, unclassified military manuals and introductory chapters in a limited number of Logistics Engineering text books. Several papers addressing some of the many specialty aspects of ILS can be found in the Proceedings of the Annual Symposia on Reliability and Maintainability sponsored by the Institute of Electrical and Electronics Engineers (IEEE) and the proceedings of the Society of Logistics Engineers (SOLE) International Logistics Symposia. Nevertheless, the subject has been largely in the domain of Defence Departments and their military equipment contractors and consultants for several years. Many of the detailed descriptions, requirements and weapon system specifications are thus subject either to security classification or proprietary confidentiality. LSM, being largely

conceptual, has not yet been addressed in the open literature.

By way of introducing ILS and logistics in general, one can note that Benjamin Blanchard from the Virginia Polytechnic Institute and State University, the widely acclaimed "guru" of logistics and author of several definitive texts on the subject, has stated that logistics is a complex and wide ranging field. When addressing the subject, one usually thinks of large, complex systems in the defence sector or perhaps a distribution capability for consumable products in the commercial sector. But he states that this is changing and that applications of the principles are now more widespread than ever. (Blanchard, 2, 1986)

Blanchard and Lowery (1969) had noted even earlier that the principles of ILS, particularly reliability and maintainability, were becoming better known and were starting to be applied in general industry as well as in the defence industries, principally to counter problems of increasing costs.

Blanchard (1, 1986) identified the principal elements of ILS as being reliability and maintenance planning, manpower and personnel, training and training support, supply support, test and support equipment, technical data, facilities, computer resources support, transportation and handling, and design interface requirements. When these elements are considered collectively in a formal manner, the cost of supporting a system over its life cycle is reduced. The fact is that support costs over the life of a system are typically many times the procurement costs. The simple message is to consider this when designing the system and make sure that the system can be supported at the least cost while still maintaining its operational capability.

In order to achieve the objectives of ILS, Logistics Support Analysis must be performed. Blanchard (1, 1986) described LSA as a design analysis tool employed in the early phases of system development. It is an iterative analytical process by which the logistics support necessary for a new system is identified and evaluated. The Logistics Support Analysis Record (LSAR), an output of LSA, is the identification of and justification for logistics support resources such as quantities and types of spare/repair parts, test and support equipment and numbers and skill levels of maintenance personnel. These general headings are further discussed under the sections titled ILS and LSA and in Appendix A.

Many reports and working papers addressing particular aspects of ILS or LSA exist within procurement and engineering divisions of the US Department of Defense and Canada's National Defence Headquarters. However, they are considered to be of little value in allowing personnel unfamiliar with the concepts to acquire a good understanding of the subject. A review of the literature of maintenance and reliability and maintainability (R and M), key elements of ILS, will help to establish an understanding of the foundations of ILS, which in turn are required to understand the need for a performance monitoring system such as LSM.

3.2 Maintenance

Maintenance has been defined by Blanchard and Lowery (1969) as: "all actions necessary for retaining an item in, or returning it to a serviceable condition". In their study on attitudes by senior management towards maintenance, Pottinger and Sutton

(1983) found that a wide spectrum of industry see maintenance as something which produces nothing at an ever increasing cost and, therefore, is to be treated negatively and as a nuisance. In both the private and the public sector, maintenance, either in repairing a breakdown or necessitating shut down for preventive maintenance, has long been perceived as a bother and a poor cousin to operations. Geraerds (1985) studied the effects of this downtime in terms of costs and lost production. Not surprisingly, he determined that greater costs resulted when corrective maintenance actions were required to repair a fault than would have been incurred if routine and scheduled preventive maintenance had been conducted (likely detecting and correcting the fault before it became catastrophic). Scheduled preventive maintenance also avoids the ancillary problems (and associated hidden costs) of making up for unscheduled downtime, wasted production line manhours, unanticipated stock levels and difficult customer relations if deliveries are subsequently disrupted.

Joshi and Gupta (1986) make a case for using historical data on equipment failures to determine when, in the production cycle, it is most advantageous for equipment to be removed from service for maintenance so that the actual costs of maintenance are minimized, a key management objective. Kelly (1984) points out that in industry, the maintenance management functions of forecasting, planning, scheduling, organizing and controlling maintenance actions are, after all, really no different from the key functions of managing production or personnel. In most industries, the bottom line of controlling costs and optimizing production prevails.

Pottinger and Sutton (1983), however, determined that, even though the maintenance

manager could legitimately justify the need for maintenance, he found himself in a constant "fire-fighting" role despite all the management systems at his disposal. Much effort was going into corrective and preventive maintenance routines based on maintenance systems that received their data on condition monitoring information that did not inform the managers what margins on performance actually existed, only that the data indicated that something out of the ordinary was being reported. Often the maintenance information system did not pick up or highlight the real downstream effect of the performed or neglected maintenance. Coutinho (1980) found that the fault in many cases was improper interpretation of the data. That is, the data was available and useful in writing historical reports but was not being used to its full potential in providing a view to what future equipment performance could be anticipated.

Blackney and Watts (1982) noted that Defence Departments and industries such as the aircraft industry recognized the need for accurate data and subsequently built up data banks over a number of years through the adoption of formal reporting procedures. These organizations have used the feedback from this data in their information systems to concentrate on the tasks which really need to be done and not simply to follow the maintenance recommendations of the manufacturers. Downs (1984) further elaborates on this point by stating that there is a requirement to focus on those items that are most failure-prone (as determined by the collection of failure rates) and to institute a program of monitoring their actual performance. He recommends the formulation of models to predict system parameters so that trade-off options can be presented to management. This means that the actual performance of the equipment should be the basis of allocating

maintenance resources and establishing maintenance schedules. This type of approach is exploited by LSA with the Reliability Centered Maintenance analysis.

Thamhain (1984) sees that with increasing system complexity, the large number of multi-disciplinary skills required, the large number of subcontractors involved and the perennial time constraint, today's project management programs dictate that management methods different from those previously used are required. Blanchard (1986) views this as a requirement for more effective and efficient management of resources, management that incorporates logistics support considerations in the early phases of system/product planning and design. The military and the aircraft industries had begun to demand a bottom up approach to maintenance from the design phase onward, supported by meaningful and relevant maintenance data, both from the manufacturer and from their own experiences in the actual field use of the equipment. Many companies in the aircraft and surface transport, communications and electronics industries as well as the Defence Departments of several Western countries, therefore, progressed from maintenance in its strictest meaning to the broader discipline of Reliability and Maintainability (R and M).

3.3 Reliability and Maintainability

Reliability is defined by Von Alven (1964) as: "the probability that a system will perform its intended function for a specified time interval when used under stated conditions". The objective is to extend that time interval of the equipment to the greatest degree possible. This is normally accomplished by selecting highly reliable components and sub-assemblies for inclusion in the design of the weapon system or equipment. Mean

Time Between Failures (MTBF) is one of the most well known reliability parameters.

Maintainability is defined as: "a characteristic of equipment design and installation which is expressed in terms of ease and economy of maintenance, availability of the equipment, safety and accuracy in the performance of the maintenance actions". The objective of maintainability is to design and develop systems and equipment which can be maintained over their life cycle in the least time, at the least cost and with a minimum expenditure of support resources without adversely affecting the item's performance or safety characteristics (Blanchard and Lowery 1969).

Together, R and M (sometimes referred to as Reliability, Availability and Maintainability, RAM) are characteristics of design which influence operational effectiveness, logistics support requirements and life cycle costs of a system. Schmitz (1987) acknowledges that a premium must be paid in the initial procurement costs to incorporate R and M considerations into the equipment design. This increment will, however, be more than offset by the economies that will be generated over the entire life cycle of the equipment.

Dhillon (1, 1983) discusses the background of R and M principles. He found that maintainability had its roots in the U.S. military services when the results of reliability programs of the late 1940s and early 1950s indicated that 100 percent reliability was an unachievable goal. It had become apparent that maintenance requirements could not be eliminated even though the life of military equipment was being prolonged by the reliability programs. Maintenance costs were approaching one third of all operating costs and nearly one third of all personnel were engaged in maintenance or support functions.

Military specifications established early definitions of R and M and the qualitative requirements to be followed by the defence equipment industrial contractors, however, there was no real coordination or standardization of definitions between the different armed services (Army, Navy and Air Force) and confusion ensued. In 1966, in an effort to standardize R and M, two publications of military standards (MIL-STD-470 and 471) and a military handbook (MIL-HDBK-472) were released by the U.S. Department of Defense in association with the new concept of Integrated Logistics Support. These presented a better definition of maintainability, its parameters and its methods of measurement. They were principally designed to give the necessary guidelines to military equipment suppliers seeking to bid on military contracts, regardless of the service for which the equipment was being purchased.

Dhillon (2, 1983) concluded from this that while more could be done, top managers of the defence industries were now becoming acutely aware of the increased efficiencies that resulted from R and M considerations. He stated that R and M and management were becoming inseparable in improving overall system performance.

Blanchard and Lowery (1969) stated that R and M was obviously an important factor in the (then) new ILS scheme. It enables the management objective of providing the controls which help to ensure that the customer receives a system that will not only meet performance requirements, but one which can be expeditiously and economically supported (with test and support equipment, spare/repair parts, transportation etc.) throughout its programmed life cycle.

From a Canadian perspective, it is interesting to note that Canadian Forces Publication

180 (1977) recounts that the Canadian Armed Forces, also in the late 1960s, was proposing a parallel system called Development of Integrated Logistics (DEVIL) which had similar objectives of integrating maintenance with supply and transportation.

Financial constraints and the delays involved with developing the embryonic integrated data system forced the abandonment of the initial DEVIL objectives in the early 1970s. Supply data development (for provisioning) was not sufficiently advanced to allow it to be merged with the maintenance data (for replacement repair parts inventory requirements) and transportation data (to efficiently move the supply items from the warehouse to the field). The DEVIL program was subsequently pared back to less ambitious objectives and ended up concentrating on supply alone, the area where most progress had been made. Today it exists as the Canadian Forces Supply System, CFSS, which supports the entire inventory of weapons and equipment systems, individual items and repair components for the Canadian Forces.

As automation increased in the Canadian Forces, Maintenance Management Information Systems (MMISs) were introduced independently during the early 1970s for the various components of the Forces (Land, Sea, Air and Communications). While these MMISs today are well established and accomplish their mandated tasks, they are all virtually stand-alone systems having limited "interoperability". The legacy of DEVIL has been the identification of the problems related to integrated support which today's technology can now address. For example, MacFarlane (1988) states that the MMIS upgrade programs that are currently under development have the objective of "interoperability" firmly established. The next generation of MMISs can be expected to

be capable of readily exchanging data with each other and with the CFSS.

3.4 Integrated Logistics Support

As information systems matured and became more pervasive in the late 60s and early 70s, particularly in the U.S., the maintenance community saw a change from maintenance and R and M to the larger, more universal concept of Integrated Logistics Support (ILS). Biedenbender, Meyer and Ruppel (1985) saw this as the turning point that contributed to the growing linkage between the R and M (design engineer) communities and the support and general logistics (end user/fixer) communities which had heretofore largely been two solitudes. With ILS, data concerning a system could now be used equally by both in the overall development of the system. Consideration of the many various logistics support elements associated with developing a system, ranging from technical publications and transportation to the training of the technicians, were seen as important components now sharing the stage with R and M. Jeffery (1987) considers that improving reliability and maintainability (i.e. supportability) are the principle ways to maximize return on investment for technology developers. He further states that R and M should be considered equally with cost, schedule, and performance in the development of future weapon systems. Nondorf (1986) notes that greater emphasis on supportability functions to reduce the total life cycle costs now require the logistician to influence the design as early as possible to ensure that supportability is designed into a system. Blanchard (1986) continues to advocate the importance of R and M as he did in Blanchard and Lowery (1969), but now from the perspective of the ILS concept where maintainability is but one,

though vital, consideration among the several logistics support activities noted above.

Blanchard (1986) suggests that innovative managers in non-defence industries are now also beginning to realize the advantages to be gained by adopting the ILS process. They can see that Defence Departments and their industrial suppliers have over the years laboriously worked out a process to contain enormously expensive defence expenditures, expenditures which have come under close public scrutiny and accountability. They can see that by following the same principles, they can gain a competitive advantage for their products. Lyon and LaSala (1984) agree that the disciplined approach of an ILS-type program, where supportability influences design, can increasingly be found in many non-defence industries, citing the automotive industry in particular.

Peters and Waterman (1982) developed the "Excellence" principle for business, a principle which focuses on the customer, innovation, people and leadership. LaSala (1986) discusses the application of the "Excellence" principle in the implementation of the "Carlucci Initiatives" of 1981 in which the then U.S. Assistant Secretary of Defense sought to improve the military acquisition process by merging the techniques proven in industry with the U.S. Defense Department's expertise in reliability and maintainability. Goldstein and Herner (1986) note that while the support related logistics engineering community identified the need to influence system design long ago, the Carlucci Initiatives gave reliability and support considerations the very high profile, priority and visibility needed. Frank Carlucci, on being appointed Secretary of Defense in late 1987, retained his interest in cost effective program management as offered by ILS and Dick Cheney, the Secretary of Defense in the Bush administration, has indicated his continuing

support for the now well established process of ILS. Starting in 1981 and continuing today, top management in both the U.S. DoD and the defence industries have, therefore, been giving ILS an increasing amount of attention.

The Systems Management College ILS Guide (1986) states that experience has repeatedly demonstrated that emphasis on readiness and supportability in a materiel system must start with the earliest activities that establish the general characteristics of the system. During these ILS activities, the program requirements are defined and system performance characteristics and objectives are established. Readiness and supportability are inextricably bound to these early activities. Prior to program initiation, cost drivers and supportability problems of existing systems provide the basis for continuing logistics R and D and the focus for improved performance in the new system. Blanchard (2, 1986) goes on to state that engineering and management societies have now embraced the ILS concept and specialty courses in the subject are increasingly being conducted at military service schools and some universities and colleges.

Giordano (1981) reminds us that ILS is a logistics management concept that has evolved to address the support considerations for equipment and weapon systems. However, he suggests that more needs to be done by upper management in industry since, early in the acquisition process, when support authority is most needed for ILS (albeit that ILS has a lower profile), resources are too easily allocated elsewhere to solve more urgent and pressing problems. In other words, since the benefits of ILS will not be felt until the system has developed further downstream, the temptation exists to utilize earmarked ILS resources for other, more immediate needs.

MacManus (1984) looks at the same issue and states that ultimate savings in Canadian defence dollars could be achieved by ensuring that the design of the weapon system or equipment considers the various elements which would be required to support it, such as spares provisioning, training and publications. He feels that the country must spend, or rather invest, the ILS dollars today in order to save many more on the system tomorrow. Now, MacManus (1984) does not see ILS as a panacea for the problems related to the acquisition and support of defence systems. Instead, he states that ILS ensures that by having logistics considerations influence design, and by considering interrelationships between categories of support, the greatest degree of supportability will be achieved for the lowest cost over the life cycle of the equipment or system. Jeffery (1987) agrees that the emphasis on incorporating supportability considerations into the design of defence systems is the essence of the discipline of ILS. He further notes that Logistics Support Analysis (LSA), whose components are key activities in any ILS program, is intended to provide a single and uniform approach for integrating supportability requirements into system requirements and design.

3.5 Logistics Support Analysis

Kline (1984) calls LSA the most critical part of the overall ILS process. He notes that it is performed to examine all elements of proposed designs to determine the logistics resources required to keep a design useable for its intended purpose throughout its life cycle. The ultimate objective of LSA is to influence design such that the operational objectives of the design may be achieved while optimizing the utilization of constrained

resources such as manpower, support equipment, cargo space and cost.

MacManus (1984) views LSA as a process used prior to and during the acquisition of a defence system to identify the specifics of some of the ILS elements required to support the end item being procured. It is used in optimization and trade-off analyses to obtain reliable, maintainable, transportable and supportable material at the lowest cost. Blanchard (1, 1986) similarly views LSA as constituting the integration and the application of various techniques and functions to aid in the evaluation of alternative system/equipment design configurations and trade-offs to arrive at a preferred solution.

Nidever (1987) somewhat cynically points out that while the objectives of ILS are lofty and pure, historically, logistics influence on design has been more talked about than has been actually achieved. He states that design influence is caused by a combination of actions accomplished by both the end users (combat developers) and the design engineers. LSA can only effectively influence design if the LSA contract is followed closely, up front in the systems development phase of the life cycle with the full cooperation between those two groups. Otherwise the logistician will be put in an unenviable and expensive catch-up position for the remainder of the life cycle.

Biedenbender, Meyer and Ruppel (1985) note that MIL-STD-1388-1A, the U.S. military standard for LSA, calls for a structured format consisting of a data element dictionary, data records which capture usage, reliability and maintainability data, other data essential to the development of detailed requirements for ILS elements and a variety of summary reports for different users which can be produced from the data records. MacManus (1984) states that LSA is not a single model or procedure which one can use

to determine the level of support. Rather, it is a number of individual analyses which take different aspects of the required support into consideration. An LSA program is typically tailored to meet the unique requirements of each individual program.

Several of the analyses conducted in an LSA process are briefly described in Appendix A. It can be noted that Nidever (1987) considers the Life Cycle Cost (LCC) analysis of LSA as being the single most critical baseline determinant in whether a system under development will continue or be cancelled. In other words, if the system has an attractive initial cost but an unacceptable life time support cost as determined by the LCC analysis, it is deemed as ultimately being undesirable. This has occurred recently in U.S. military programs such as the Sergeant York anti-aircraft system and the Boeing V22 "OSPREY" Vertical Takeoff and Landing aircraft (VERTOL), both of which were cancelled in April, 1989 even after several billion dollars had already been invested in their development. The principal reason for this was that neither could be economically supported for the duration of their life cycles, a conclusion that was derived from the LCC analysis of the LSA for those programs.

Normally the output from LSA is stored in the LSAR database. It can be purchased from the contractor under the terms of the acquisition contract, as has occurred in some recent Canadian Forces major defence system procurements. Nidever (1987) considers the LSAR to be a subset of the LSA documentation. It is the data set which contains the detailed engineering and logistics support requirements data gathered by the LSA process. Standard requirements, data element definitions and LSAR data record formats are prescribed in MIL-STD-1388-2A. Blanchard (1, 1986) notes that there are 14 individual

data records in the LSAR pertaining to some of the technical characteristics of the system and they are based on the work breakdown structure. Typical records are the number and types of people who are required to support the design, the maintenance tasks required, and the types, number and locations of repair parts, test equipment and tools required. Schmitz (1987) sees the LSAR essentially as being the manufacturers' forecasts and projections of the reliability of their products.

Kline (1985) states that a number of different models have been developed for LSA. These include level-of-repair (repair/discard) models, spares provisioning models and reliability and maintainability prediction models. The literature has several examples of descriptions and applications of these models such as Davidson and Landstra (1975) with A Logistics and Ranking Model (ALARM), McCarthy (1981) and Seger (1982) with the Optimum Repair Level Analysis (ORLA), DeVries and Wicker (1986) with Multi-Echelon Repair Level Analysis (MERLA), Mortenson (1980) with Queueing Graphical Evaluation and Review Technique (Q-GERT), and Kline (1985) and Blanchard (1986) with the widely acclaimed Rand Corporation's Multi-Echelon Technique for Recoverable Item Control (METRIC) and the MOD METRIC refinements of Muckstadt (1973), both of which are used for initial provisioning projections.

Blanchard (1, 1986) praises the use of models as low cost simulations to ensure that supportability is considered in the system design process, but cautions against becoming too attached to them. Lynch and Phaller (1984) note that many of the assumptions concerning reliability developed in a clinical laboratory environment simply do not stand up in the actual field use of the equipment. The "What if?" analyses in LSA models,

facilitated by the extensive use of computers, allow for rapid determination of relationships between components in a system. Ideally they can be used to avoid future problems. However, Blanchard (1, 1986) notes that models are only a tool used in decision making and cannot be considered as a substitute for experience and judgement. Sontz and Nevola (1983) imply that too often the problem of disparity between what the model predicts and what actually occurs is solved by a quick change to the software of the model. The model may now more accurately represent the real world situation at t' at point in time, however, it may still be imperfect and again be unable to explain discrepancies with the next iteration. Horn and Hall (1983) state that it is important to determine the causes of the difference between expected performance and that actually achieved so that solutions can be developed and corrective actions taken, not simply offering a quick software solution to the model. Again, experience and judgement, in conjunction with the computerized tools are the best methods for determining the differences. The identification of those differences by projecting known values into the future and comparing them with accepted baseline values is, of course, what LSM deals with.

3.6 Forecasting

In any ILS plan, many of the LSA analyses that are carried out deal with predictions of equipment performance. Forecasting failure rates and life cycle costs, for example, are central to the requirement for planning and management direction. Kolson, Stracener and Trakas (1983) found that initial spares provisioning and procurement of support

equipment based on inaccurate predictions of reliability resulted in non-optimum allocation of resources and subsequently low levels of readiness. In other words, an inaccuracy in the LSA forecast can have serious repercussions in operations. The best way to control that situation is to evaluate the LSA forecast from the perspective of field use and make corrections as necessary.

Blanchard (1, 1986) cites estimating relationships as one useful method of forecasting in LSA in which one parameter is related in terms of another. These relationships are developed by collecting and accumulating data on similar systems and correlating various individual factors to the appropriate characteristics of the new system. Forecasting techniques such as these are used to facilitate the development phase of the life cycle. For example, Kolson, Stracener and Trakas (1983) used estimating relationships for predicting U.S. Navy aircraft fleet reliability during initial and early fleet introduction of new aircraft types by utilizing the results of previous similar equipment acquisition programs. This was done since, early in the acquisition phase, the prediction process can not depend on any operational data (baselines) for the new equipment. The forecasting analysis is an iterative process involving the evaluation of different elements of the system in terms of the whole, keeping certain features constant while varying others. Blanchard (1, 1986) states that forecasting techniques are fundamental to the LSA process and allow the manufacturers to produce the LSAR which the customer can then use as the baseline for logistics support requirements.

To avoid confusion over the term "forecasting" used throughout this paper, it should be pointed out that there are really two distinctive and separate sets of forecasts related

to LSM. First, the LSA process predicts what ILS resources will be required to logistically support the system. These predictions (forecasts) are held in the LSAR which can then be used as a baseline value for comparison with actual performance. The second forecast, this one in the LSM model itself, consists of a prediction of how the "actual performance" will look at some specified time in the future based on how it has performed in the past and this value is compared with the baseline. In other words, initially the LSAR forecast can give us a baseline of expected logistics performance of the defence system. The LSM forecast then uses actual observed performance to extrapolate how future performance can be expected to compare to that LSAR baseline. It is the latter forecast which enables management to anticipate where logistics support problems may be developing with in-service defence systems.

In order to identify the difference between what has occurred and what was planned, one can react in a post-facto manner and attempt corrective action reactively, or one can aim to intervene proactively. Proactive in this sense means to anticipate where a problem may be developing and to take corrective action before the problem actually occurs. LSM forecasting is the key to proactive intervention for logistics support. Martin (1983) notes that in recent years, experts have repeatedly underestimated risk by failing to consider future unknowns. Decision-makers too often do not appreciate the value of forecasting and the insight it can give them to understanding the trends that directly relate to the risk.

For managers to be able to respond proactively, they must rely on accurate forecasts. In this case, those accurate forecasts relate to how logistics support performance can be expected to look at some future time horizon.

There are several forecasting methods available, each having its own distinctive strengths and weaknesses. A number of them could be applied to the LSM forecasting model depending on the characteristics of the data. Makridakis and Wheelwright (1978) provide a comprehensive analysis of factors to be considered in the selection of a forecasting method. They conclude that either the complex Box-Jenkins method or the more widely known and relatively simpler autoregression method⁹ both have superior strength relative to other forecasting methods for producing a forecast of medium range in the desired time horizon. Both can handle data with trend and seasonal patterns (in which category the maintenance and supply data fall) and allow for the determination of a turning point. Significantly, Makridakis (1984) subsequently determined that in time series analyses, simpler methods perform well relative to the more complex and statistically sophisticated models. In other words, results obtained from the simpler time lag autoregression technique compare favourably with those from the more complex Box-Jenkins approach. This fact was key to the selection of the forecasting technique which is employed in the prototype model described in part 6.

3.7 Data

In ILS/LSA, one of the most important steps in the analysis process is to assemble

⁹ Autoregression is a form of multiple regression, but instead of the dependent variable (the item to be forecast) being related to independent variables, it is related to past values of itself at varying time lags. Thus an autoregressive model would express the forecast as a function of previous values of that time series. From Makridakis, Spyros and Steven C. Wheelwright. *Interactive Forecasting: Univariate and Multivariate Methods*, 2 ed. San Francisco: Holden-Day Inc. 1978. Page 577.

the appropriate input data. Blanchard (1, 1986) states that when evaluating a typical system or equipment item, it is necessary to consider operational requirements, the maintenance concept, design features, production/construction plans, anticipated logistics support, and so on. As noted earlier, in the initial phases of system development, available data are limited, thus, the analyst must depend on the use of various estimating relationships and projections based on past experience covering similar type systems. Jeffery (1987) identifies current data banks, which provide historical information from field usage on existing equipment and systems, as a valuable source of data for this type of analysis. Giordano (1981) notes that a major shortcoming in the U.S. Department of Defense ILS/LSA process is the number of similar but separate data banks that exist. He recommends establishing a linking data bank network to improve data commonality and therefore allow for lessons learned to be used across the military services. One attempt at doing this is about to become operational. Fry (1989) recounts the success of the U.S. Air Force's Logistics Management System which corrects many problems of 1960s vintage logistics computer systems. There is some interface with U.S. Army logistics systems in the development of a joint engineering data repository and further inter-service applications are being explored.

The Canadian Forces also maintain several similar but separate data banks on existing equipment and while several upgrade programs are either planned or currently underway, the scope of the USAF Logistics Management System is much larger than anything planned for the Canadian Forces. As Parsons and Duchesne (1981) point out, the comparatively small Canadian Forces are integrated under a single structure of command,

personnel and logistics systems in order to reduce the size of headquarters staff. The three basic elements of air, sea and land still exist, but within this unified structure. Each element maintains its own maintenance management information system (MMIS) database on equipment/systems that are specific to it.

Canadian Forces Publication 180 (1977) states that, while not an MMIS, the Canadian Forces Supply System (CFSS) is centered around a huge repository of data on inventory, location, cost, suppliers and consumption rates of all items used by the Canadian Forces. The data from the CFSS and MMISs is vital to any ILS/LSA process not only for providing historical data for analysis, but also for allowing determination of trends in reliability and other logistics considerations of weapon systems and other equipment. The latter usage requires sophisticated techniques of forecasting and the ability to extract and process large quantities of data and present the findings in a form desired by the user. Thomas (1984) suggests, however, that a report which considered the data not only from such a historical data repository, but also compared it to the projected logistics requirements anticipated by the manufacturer in the LSAR, would be more useful.

Dhillon and Reiche (1985) identify the MMISs of the Canadian Forces: Ship Maintenance Management Information System (SMMIS), Land Ordinance Maintenance Management Information System (LOMMIS), Aircraft Maintenance Management Information System (AMMIS), Test Equipment Maintenance Management Information System (TEMMIS), and Electronics Maintenance Management Information System (EMMIS). These MMISs all function along similar lines, however, they are not interoperable. For example, the AMMIS Training Handout (1989) states that its database

has been designed to enable the collection and analysis of corrective and preventive maintenance experience data at all three levels of maintenance (squadron, base and contractor). The data collected includes descriptive information on the item being maintained, coding to describe the nature of the fault, fix and fault detection method, man hours associated with the task and details on the items removed and installed. This database can compare present experiences with past experiences to perform trend analysis (albeit without a baseline to compare it to). The other systems operate in a similar manner and plans exist to upgrade a number of them.

Thomas (1984) discusses a "Unified Data Base" approach that the U.S. Air Force is researching in association with Clemson University. This ambitious program seeks to enable the U.S. government and contractors to compare requirements, allocations, predictions and measured results in a consistent manner. It would permit early identification and resolution of specific problem areas on a management-by-exception basis. The program would also permit early verification of the LSAR even in areas where no problems are thought to exist by comparing it with other baselines calculated for similar systems, again using estimating relationships. Many of the features described by Thomas (1984) have subsequently been incorporated in the USAF's Logistic Management System (Fry, 1989).

The EMMIS Activities Handbook (1989) states that one of the main objectives of the EMMIS system is to depict the relationship between predicted reliability (generally from the manufacturer's projections in the LSAR) and actual equipment reliability and maintainability levels (from EMMIS and CFSS data). Similar objectives exist for the

other MMISs. Currently, the Handbook goes on to state, the comparison is only performed when a specific comparison report is requested. Considering that real-time access to the CFSS data has not yet been facilitated, the LCMM staff must request printouts from both it and the EMMIS database for any particular equipment they wish to study. They must then manually go through each line to evaluate whether a trend is developing. This has proven to be very time consuming; such reports may take up to two weeks to be processed.

The XMCO company's DND Maintenance and Support Program (MASP) study (1988), determined that a major contributor to the existing management difficulties in supporting aircraft and other weapon systems is the quantity, disparity, and diffusion of maintenance and support documentation, information systems and data bases. Consequently, materiel and supply managers in NDHQ spend an excessive amount of time searching for the data required for management decision making. Much of this fragmented data is poorly maintained or not updated at all. Improvements are needed to minimize the wasteful use of highly skilled resources-- the materiel and supply managers. The study recommends the use of the LSAR in relation to existing supply and maintenance data bases in order to verify that the defence system maximizes the use of existing assets, personnel and skill levels, support and test equipment, and training. Similarly, verification is required to ensure the system design maximizes system safety, availability, and supportability through many of the LSA analyses associated with the ILS plan.

The overall recommendation of the MASP study is for the creation of a rationalized

Maintenance Support Program database as a source for planning and in-service management for each major defence system. This recommended database would gather its data from existing MMISs, the CFSS and the LSAR and could be used with a performance assessment system such as LSM. Notably, the MASP study states:

A recent development in ... program assessment is ... a Logistics Support Monitoring database. Through continuous monitoring of selected maintenance and supply data elements and comparison with predicted values ... it would allow managers to prevent rather than react to problems. LSM will require the interaction, either manually or automatically with the MMIS and CFSS databases. Note: presently no LSM database has been developed.

The remainder of this thesis discusses the design criteria that are necessary for developing an operational LSM system. A preliminary prototype is presented in order to exhibit that the concept is feasible.

4. MANAGEMENT CONSIDERATIONS RELATING TO AN LSM SYSTEM

4.1 General

LSM is defined as the proactive use of operational, maintenance and supply data to alert the Weapon System Manager (WSM), Life Cycle Materiel Manager (LCMM) and other management staff to actual or impending logistics support problems affecting the defence system.¹⁰ It monitors the effectiveness and efficiency of the ILS program with a view to identifying where management intervention is necessary and where changes, if required, in the logistics support package should be made.

LSM is not a new concept, the principles having been introduced in 1986 in the DND Aircraft Serviceability Review (ASR) under the title "Automated Aircraft Performance Monitoring"¹¹. There has recently been renewed interest in getting more out of the MMISs in order that this data can be of greater use to managers responsible for the life cycle of the ILS program for their systems. The ASR project pointed out that the regular monitoring of maintenance and supply parameters was required to determine the reasons for the unsatisfactory serviceability rates of some aircraft fleets. The ASR critique showed that most of the required data is currently available in the maintenance data bases, however, the user-friendly manipulation of large amounts of data to provide meaningful information (on which action can be taken) was and is missing. LSM promises to provide this missing link.

¹⁰ DND ILS Course, 1987.

¹¹ Eyretechnics Co. Ltd. *op cit*

The lack of interoperability of the data bases has also been a problem. With the new initiatives in integrating the different computer systems underway (a key element of the Equipment Systems Management project at NDHQ¹²), an LSM system should now be able to be designed.

Although the principles of LSM can be applied to the logistics support program for any major defence system, an aircraft weapon system setting has been selected for many of the examples in this study to determine the design criteria for an LSM system.

4.2 LSM Concepts¹³

LSM is seen as an enrichment to ILS. It would carry out a comparative analysis of LSAR or other baseline data with historical maintenance, operations and supply data (available from the various maintenance management, operational and supply system databases) in order to give decision makers indications where problems could be anticipated. Focusing on different criteria (parameters), LSM would compare "real world" performance to that anticipated and alert staff to significant variations. This type of projection would have far reaching implications, not only on the obvious repair parts inventories but also on several other aspects of ILS such as the training of technicians, technical documentation, transportation and physical resources.

It should be noted that the role of LSM will be to monitor, not to investigate,

¹²ESM Project Manager briefing to the Director General of Communications and Electronics Engineering and Maintenance, NDHQ, Ottawa, 2 February 1990.

¹³ The source for LSM concepts derive from EH Industries (Canada). *DND New Shipborne Aircraft Definition Contract, CDRL 607*. Ottawa, 1989.

although it will likely provide indications on where the investigation for the reasons for unacceptable performance should start.

A fully functioning LSM system will require a commitment by management to proactive intervention. In order to allow for a proactive doctrine, forecasting plays an important role in LSM. The forecasting component would analyse time series observed historical (field) data to determine a trend. The source data will have been formatted in terms of performance monitoring parameters. LSM would then determine how actual performance has fared by comparing the forecast based on past data with the baseline value. If the forecast ventures outside a predetermined threshold (which is relative to the LSAR or some other prearranged baseline and is set by the user) within a specified period, an alert would be triggered advising the logistics staff that further investigation is required to determine the cause(s) before the performance becomes unacceptable. For instance, theoretical reliability data (contained in the LSAR database) would be automatically compared with the historical spare parts consumption data and a forecast of future consumption based on that data would be made to enable supply and maintenance staff to project whether stock levels of spare parts are adequate now or will be adequate at some future time of interest. Similarly, the staff would be able to determine whether worrisome trends were developing in the performance of existing systems because of an unusual number of repairs of a certain kind to one particular subassembly in a system.

The user would also be able to request a trend analysis at any time, even though no alert condition was detected. The form of the alert and trend analysis would be identical,

the only difference being that the former would occur when LSM detected or forecasted an alert condition and the latter could be requested by the user/analyst in the absence of an alert in order to provide room for interjecting human judgement into the process. LSM would, therefore, increase the planning staff's ability to anticipate problems, thereby allowing them to take preemptive action regarding a developing problem before it became critical. Application of LSM would thus increase operational efficiency.

It cannot be expected that defence systems will continuously reflect a constant manufacturer's LSAR or other baseline. Therefore, a formula should be developed to determine threshold values (alert levels) of acceptable performance relative to the baseline that is being used for the equipment under study. A "window" of acceptable performance would thus be generated. If the alert level is triggered, it should be a warning that the baseline itself is in danger of being violated. Alert levels protect the baseline. This is done to give some degree of flexibility to the system and to give warning of a worrisome trend before the critical event occurs. For example, if the baseline for the Mean Time Between Failure (MTBF) parameter is expected to have a value of 1000 hours for a specific system, the threshold might be 800 hours (where the logistics resources of technicians, spare parts, workshop space, etc. can still be stretched to accommodate the repair task(s)). Even though the initial determination of threshold values would be by a formula whose criteria were set by the maintenance manager, different values may have to be inserted if too many false alarms are generated. Conversely, if no alerts are triggered, the analyst should be reasonably certain that it is because the system under study is performing well, not because the threshold has been set too high thereby allowing

a true alert to be missed. Values based on experience and a "rule of thumb" may prove to be more appropriate. Determining the threshold values will, therefore, have to result from fine-tuning.

A simplified representation of the LSM technique is shown in figure 3. Observed values of the parameter being studied are plotted and it is seen that a straight line approximates the data points. The window of

Figure 3 The LSM Technique

acceptable performance is

shown with a threshold value (alert level) where unacceptable performance is expected to begin. An alert that is produced today ("Present") would show that a worrisome trend is developing even though performance ("VALUE OF PARAMETER") is still within acceptable limits. There is still time to react before the forecast line crosses the threshold value, indicating unacceptable performance at some specific future time. This simplified diagram depicting a linear forecast and baseline is shown for illustration purposes only.

The ILS concept promotes the advantages of better coordination and liaison between maintenance and supply staffs. Many potential problems between these two groups can be avoided by adopting a system where a rationalized set of parameters can be monitored

by these staff on a regular basis.

The LSM system should be designed so as to monitor a set number of these parameters. Each parameter has a theoretical/predicted value and an actual/field value that is obtained by the processing of data collected from the field. These values should be compared and an alert condition, as defined by the user, should be triggered if a significant discrepancy exists. An alert condition is simply a warning that the computer would give to the logistics manager that a predetermined parameter value either has been exceeded or can be expected to be exceeded. The logistics manager, having been cautioned, then proceeds to investigate the cause(s) and takes the corrective action necessary, or disregards the alert if, in his judgement, it is not warranted.

Alert conditions can be triggered by one of three different ways:

- a. comparison with a baseline value, which in many cases would be the predicted value taken from the LSAR. If the most recent actual parameter value falls outside the set threshold limits, an alert condition is triggered;
- b. comparison with a norm or management objective, which in most cases would be a target established by senior maintenance management. This value could be stored in the LSAR or be given independently. Again, if the true value falls outside of the envelope of acceptable performance by crossing a management objective threshold, an alert condition is triggered; and
- c. extrapolating the value of the parameter by statistically forecasting its future value based on past performance. If the forecast shows a trend where the value will exceed the set threshold limits at some time in the future, an alert is triggered.

The first two methods are reactive and the third is proactive.

Figure 4 illustrates how the overall LSM system is conceptualized. The diagram indicates that various databases feed the LSM system where the field reported data is initially formatted in terms of the desired parameters.

Figure 4 The LSM System

The comparative analysis

("A") occurs between the baseline value (say, the LSAR value and/or a management goal) and the historical data and/or with the forecast statistically determined ("B") from that historical data. The forecast module ("B") is shown in a dotted box since LSM could be designed to exclude the forecasting component and simply compare past real performance with that expected (cases a. and b. above). After the system (with or without the forecasting module) has detected a difference of sufficient magnitude to trigger an alert, an alert report is generated for the attention of the analyst who ordered the LSM run.

The forecast module, which is the essence of proactive intervention, could be based on any of a number of different statistical techniques such as exponential smoothing, Winter's seasonal model, Box-Jenkins or even regression analysis. The prototype forecasting model in this thesis uses time lag autoregression simply to demonstrate that

LSM forecasting is feasible. In practice, it may be found that other forecasting methods are more suitable.

An LSM computer program should automatically perform a forecast on the observed historical data and compare it to the baseline predicted data in terms of a specific performance parameter selected by the logistics analyst. The program could be iteratively run for any number of parameters selected for a particular equipment. Considering that many usage and failure rates are seasonal by nature (for example, jet trainer aircraft or armoured bridge-laying vehicles are used more heavily in the summer training period than in the winter), the resulting forecast of performance should also show the seasonal fluctuations. This seasonalized extrapolation (forecast) will have to consider this when determining future trends in performance according to the parameter specified.

Figure 5 depicts the use of seasonalized time series data which can be expected for many defence systems/military equipment. The data points can be seen to have a cyclical pattern. Both the baseline and alert level are adjusted with the seasonalization factor which has been calculated

Figure 5 LSM With Seasonalized Data

from the data points. The forecast (based on past performance) that is conducted today ("Present") determines that the expected future performance ("VALUE OF PARAMETER") will cross the alert threshold (indicating unacceptable performance) at a time within the horizon of the forecast, the criteria for generating an alert.

Defence systems (consisting of weapon systems such as fighter aircraft, tanks or frigates and defence support systems and equipment such as radars, fire control and communications networks) are considered to be prime candidates for LSM analysis in a military context. Manufacturers' estimations of reliability of these systems may be based on clinical laboratory or even simulated field conditions, however, they rarely match the actual performance of the equipment in protracted and rugged field use. LSM relates this reliability LSAR data (or some other baseline value) to "real world" data in terms of criteria (parameters) which the logistician wishes to monitor.

Parameters such as Mean Time Between Failure (MTBF) for a system, Maintenance Man Hours per Flying Hour (MMH/FH) for a particular type of aircraft or Mean Time Between Replacements (MTBR) for a vehicle fleet could be selected for LSM analysis. The analysis would be performed on a particular set (or family) of like equipments in order to establish an overall trend. MMH/FH analysis on a single aircraft, for example, would have little validity in determining the performance trend for all aircraft of that type.

A number of parameters are explained in some detail further in this thesis to demonstrate the importance they serve in the overall design of an effective LSM system. They are representative of some of the parameters listed in Appendix B which logistics

support staff have indicated as being required by them¹⁴. Different LCMMs for different systems have similarly indicated that different parameters are most useful to them. For instance, aircraft weapon systems staff might determine that Maintenance Man Hours per Flying Hour (MMH/FH) is an important trend indicator to them for a particular type of aircraft. Communications engineering staff, on the other hand, might find that Mean Time Between Replacements (MTBR) for specific printed circuit boards in a certain family of radios are more important. LSM should be able to accept any parameter that can be calculated from the summarized data provided in the LSAR or other baseline and the actual performance collected by the CFSS/MMISs.

The historical MMIS and CFSS data should allow LSM to project forecasts of the particular defence system performance based on the parameter chosen by the staff as being the key indicator. The LSM analysis would point out whether there is deteriorating logistics performance, or if there is a forecast of this developing for the equipment being analyzed. If so, maintenance managers would then determine if further investigation to the causes would be required by experts to determine if and what corrective action should be taken. Such preemptive action could consist of ordering an unscheduled maintenance task to replace a component that is demonstrating a high failure rate, or recommending the acquisition of a different component which has a higher degree of reliability.

An LSM system should also be able to identify the "worst contributors" to a particular parameter that is showing an existing or potential problem. These "worst contributors"

¹⁴ A committee of nine aircraft systems LCMMs determined the parameters shown in Appendix B under the auspices of DAS Eng of NDHQ in July, 1988.

are the sub-assemblies or components that, due to their inherent lower reliability and comparatively poorer performance, cause a disproportionate number of repeat failures of a particular system thus causing the parameter being studied to indicate unacceptable performance. For example, if the MTBF parameter for a particular jet engine is repeatedly generating an alert, LSM should be able to identify that, say, the fuel control unit is the greatest contributor to the failures, the compressor is the second worst contributor, the turbine is the third etc. This would be done simply by determining the number of maintenance incidents that were caused by those sub-assemblies. By analysing the input data, LSM should identify, in order of priority, which sub-assemblies/components were most to blame for the unacceptable parameter value, the "worst contributors". Having been thus alerted, the maintenance manager would conduct his investigation to the cause(s) and he would then direct what corrective action was to be taken. "Worst Contributors" as a design criteria is discussed further in Chapter 5.

LSM should make post-acquisition phase use of the LSAR data. In this manner, LSM measures the effectiveness of the logistics support in relation to what was anticipated. If the LSAR projected data is found to be consistently out of line with what is actually happening, LSM can indicate that detailed analysis regarding the cause is necessary. This could entail in-depth consultation with the manufacturer, and in extreme cases, could lead senior management in DND to direct that the LSAR data be changed to reflect more realistic values. The latter has serious implications since the legal aspects of conforming to the warranty terms of the acquisition contract would be brought into play. Revising the LSAR value could entail repeating portions of the very expensive LSA process,

expenses neither the manufacturer nor the client would wish to bear. Changing an LSAR value early in the system life cycle, therefore, would be expected to be a measure of last resort. More likely, degraded performance would occur after the warranty has expired and the LSAR value would be adjusted by management to reflect the latest true observed reality as the system matures in the in-service phase of its life cycle.

It must be noted that the final results of an LSM analysis will only be as useful or accurate as the timeliness and quality of the data which is input. Without timely data, trends are identified too late. Without accurate data, the whole operation becomes meaningless at best and misleading at worst.

With LSM, the users, who are decision makers in both project management for new defence systems and life-cycle materiel management of existing systems, are provided a forecasting tool which analyses data according to the preprogrammed parameters and gives them a head start in finding and correcting problems. It must be noted that these users are required to interact with the LSM system; they must use the tool and determine whether or not to accept the results and they must make the management decisions required to correct actual or anticipated problems. LSM does not automate this important management function, human intervention is still required to make the decisions, decisions made necessary by the warning that the LSM tool provides. Convincing the ultimate users, primarily LCMMs, that LSM will assist them in their functions should do much to overcome the resistance to change characteristic that would otherwise be expected.

4.3 LSM Relating to ILS.

Of the ILS elements identified in Appendix A, only some are considered to be suitable for monitoring. LSM can monitor only those elements which have capturable data associated with them, data which can then be used to identify areas where intervention is necessary to improve that element's effectiveness.

The ILS elements of maintenance, supply, personnel and training are considered to meet the criteria of having capturable data and are seen to be suitable for monitoring in terms of parameters (listed in Appendix B). As was previously noted, a military aircraft weapon system context will be used to illustrate the concept of LSM parameters.

a. Maintenance Monitoring - Several aspects of the maintenance of aircraft weapon systems can be monitored by selected parameters. The effectiveness of maintenance, for example, can be measured in terms of the total number of failures, while the efficiency of maintenance could be measured in terms of manhour consumption and downtime. The data for these measurements are available from the AMMIS maintenance database and the Aircraft Utilization Statistical Report (AUSR), an operational database.

Measured on a regular periodic basis, the total number of failures, manhour consumption and downtime can be evaluated in terms of trends. These trends should help in projecting into the future the prediction of how the absolute values can be expected to compare to management goals. Depending on the rate and the direction of the change (the trend), management can decide if further investigation is warranted.

The process of monitoring maintainability parameters should be sufficiently flexible to allow for focusing on any level of assembly (from sub-system down to component), for any maintenance organization (from an austere field workshop to a contractor's sophisticated retrofit facility), and for any specified period of time. Here the success of proactive intervention depends on management's ability to review the processed information and to order corrective maintenance action to be taken where required before target values or thresholds are exceeded.

It is expected that maintenance monitoring will be the most common and popular application of an LSM system. Maintenance managers want and need a system that will tell them if and when a system will fail and will also tell them the sub-system or assembly/component that is likely to cause the failure.

b. Supply Support Monitoring - The effectiveness and efficiency of supply support can be determined by monitoring one or more of the 29 LSM parameters identified by the Directorate of Aerospace Support Engineering (DAS Eng) of NDHQ and listed at Appendix B. One such parameter, the "customer satisfaction rate" would be a good indicator of logistics support with data obtainable only from the CFSS. This means that a demand for an item submitted by a customer is filled (satisfied) within the time specified by that customer, a parameter that can be monitored from CFSS data. The "robbing rate" (described later), on the other hand, is another parameter indicative of the effectiveness of supply support, but here the data is taken from AMMIS. Other parameters could also give an indication of supply support effectiveness even if they

are not specifically dedicated to that task. Management should be very interested in the feature of monitoring supply support. It would allow for the evaluation of whether maintenance time was lost or wasted as a result of having to wait for the supply system to provide the required repair parts.

c. Personnel Monitoring - The phrase "people are our most valuable resource" is used so often in many circles that it loses its significance to many who hear it. Nevertheless, here it is seen to be particularly significant in terms of ILS.

AMMIS captures data which may be used to forecast changes in the aircraft maintenance organization establishment, that is, the number and qualifications of maintenance personnel. For example, evidence of the requirement for an increasing maintenance effort to keep the aircraft safe and operational may be obtained by monitoring manpower consumption rates, the number of technician man hours required to perform the maintenance tasks. A sustained increase in the expenditure of technician man hours is almost certainly one indicator that the system(s) being monitored is/are in decline and will continue to place increasing demands on manpower, a limited resource. Such trends are worthy of investigation not only from a personnel requirement point of view, but also from a technical point of view. The data is readily available from the AMMIS database. All manhours expended on maintenance for all various systems are reported and are added to the AMMIS historical database.

Maintenance manpower consumption rates are considered to be a good indicator

of the overall adequacy of the numbers and qualifications (skill levels) of maintenance personnel on establishment. The valuable ILS resource of personnel should, therefore, be monitored.

d. Training Monitoring - Adequate training is the final vital support component for ILS that is considered suitable for LSM analysis. Training is an on-going activity which must be seen to be meeting the needs of the maintenance community. In the area of aircraft maintenance, the effectiveness of training is perceived as one of several measures to determine the quality of maintenance and efficiency with which the work is performed.

The efficiency of the training of maintenance personnel can be indirectly monitored by several LSM parameters. For instance, the Mean Time To Repair (MTTR) parameter or the number of repetitive repairs are indicative of the adequacy of training, although there are certainly other factors that can influence MTTR or the occurrence of repetitive repairs. It would thus be necessary to investigate the reasons for unsatisfactory MTTR values and the incidence of repeat repairs to determine whether inadequate training was to blame. Consultation with the training agencies, for example, could determine whether a particular repair routine was being taught properly. If it was, training would be determined not to be at fault and the investigation would continue to uncover the true reason(s).

The other ILS elements including "technical data" are not considered suitable for LSM evaluation at this time. Despite the fact that technical engineering data is vital to maintain an adequate level of engineering support, no data system exists that can capture "Technical Engineering" data from which the adequacy of this ILS element can be determined. Packaging, handling, storage and transportation (PHST), facilities, and support and test equipment are other ILS elements that also have no capturable data associated with them at the present time. Without actual observation data, there is no means to see how those elements compare with management goals using LSM.

4.4 Description of Selected LSM Parameters

As was noted earlier, the Directorate of Aerospace Support Engineering (DAS Eng) at NDHQ has produced a list of some 29 parameters that would be valuable for Air Force Weapon Systems Managers and LCMMs to evaluate logistics support performance. It must be emphasized that the six representative parameters discussed below have been selected to demonstrate the performance measurement principles that must be considered in the design of an LSM system. Understanding the philosophy behind selecting the parameters such as these is the key to customizing others for an LSM analysis on a specific defence system. Any of the other 29 parameters could equally have been selected.

There are many other parameters that can be calculated, possibly as composites of existing ones. It is expected that as management becomes more familiar with LSM, additional parameters which are indicative of performance and trends of potentially major

consumers of ILS resources, will be developed. The following parameters have as their data source either the CFSS, AMMIS or AUSR or a combination of these three. Again, as LSM develops, it is conceivable that other databases such as those relating to personnel or training may also prove to be valuable sources of information.

Different parameters have varying significance to different analysts. A logistician studying the effectiveness of the supply system would probably be concerned with parameters quite different from those an LCMM would study in determining the effectiveness of a particular repair procedure. The following discussion of specific parameters is, therefore, intended to show the logic process that would be used to determine the applicability of a parameter for analysis. The letters in parentheses following the name of the parameter are the abbreviated form of the parameter as used by the LSM computer program "FORECAST".

a. Flying-Hours (FH) - This is the primary rating parameter for the LSM example used in the prototype and is analogous to operating hours for a tank or radar system. The number of hours that are flown are routinely reported to NDHQ via the AUSR on a monthly basis by aircraft type and by squadron totals. A comparison between these statistics and the authorized Monthly Flying Rate (MFR), provides visibility of the degree of correspondence between the authorized and the achieved flying rates.

Historically, squadrons have flown the Monthly Flying Rate, averaged over several months if necessary. Should the authorized flying rate be consistently exceeded or consistently underflown, however, serious problems may be experienced in the

effectiveness of the logistics support. Consistently exceeding the authorized flying rate will consume logistics support resources more quickly than planned. This could result in unforecast shortages, ultimately threatening the operational availability of the aircraft. Conversely, consistently underflying the authorized flying rate may also jeopardize the effectiveness of the logistics support. For example, repair and overhaul and other maintenance actions must be planned for well in advance to avoid inefficient use of resources and excessive delays in servicing the aircraft. If a major maintenance inspection by a contractor is scheduled for an aircraft expecting it to have accrued 500 flying hours since its last inspection, but it has actually only flown 300 hours, the inspection will likely have been a waste of time, scarce resources and money.

Forecasting FH may be of only limited value for most aircraft fleets since it is subject to a large number of variables. However, in a training squadron, one could assume that the total number of flying hours should not change appreciably from one year to the next if there are no other changes in the operations, training standards, number of trainees or types of aircraft. Under these conditions, forecasting flying hours may have some validity. An important assumption for an LSM system is that the activities being monitored follow a twelve month cycle. In other words, the past occurrences are a window to what will occur in the future.

Many parameters can be expressed in ratios relative to the flying rate. These ratios may be more suited to detailed analysis than the actual flying rate itself. For example, determining the maintenance actions per flying hour is more meaningful

than a statement of flying hours alone. In other words, the flying hours represent the intensity of the flying activity. By dividing an absolute parameter value by FH, one should ideally get a constant if there are no other changes. When these ratios vary, they signal changes that probably require investigation.

In appreciating the need to plan logistics support for aircraft fleets, NDHQ issues the authorized flying rates which would allow for that logistics support plan to be followed. However, the actual number of hours flown may vary greatly from that planned (although it is attempted to average these rates out over a longer period of time whenever possible). For instance, the recent airlifting of emergency relief supplies to Africa and transporting U.N. peacekeepers and their equipment to Namibia and Iran-Iraq undoubtedly was a logistics support planning nightmare for the maintenance managers of the CC130 Hercules fleet (the aircraft most used for those operations). These unforeseen requirements can sometimes be compensated for with a contingency number of hours, however, heavy unforecasted commitments cannot but disrupt the logistics support planning since they cannot be averaged out due to other non-negotiable tasks for the aircraft fleet such as the resupply of an isolated military station in the Arctic.

Nevertheless, FH is seen as an important parameter, particularly when it forms the basis for a composite parameter such as the one discussed below. It is necessary for tracking reliability and maintainability rates. Also, long term trends in the flying rate could serve as an indicator of the possible effects of logistics support resource consumption. If the total number of hours for a fleet is steadily increasing over the

years, logisticians must adjust the support plan accordingly.

b. Maintenance Actions per Flying Hour (MA/FH) - Here the maintenance actions refer to **unscheduled** maintenance tasks reported through AMMIS, and the Flying Hours refer to the total number of the fleet (or type) of aircraft in a set period. This FH data is collected by AUSR. MA/FH is a useful parameter for monitoring the reliability of the aircraft as a whole as well as the sub-systems whose operating hours are directly related to flying hours. For example, engine use is directly related to flying hours. The time spent on the ground with the engine idling or preparing for takeoff can be lumped in with flying hours. Considering that this parameter deals with unscheduled maintenance, the maintenance data must be sorted out to exclude scheduled maintenance, precautionary removals and those maintenance actions categorized as "no fault found". On the other hand, a radio transceiver could be on for many hours while the aircraft is on the ground without the engine running, drawing its power from the aircraft batteries, therefore, MA/FH would be a meaningless statistic for this equipment.

The reliability values experienced by an aircraft weapon system usually cannot be directly compared with the reliability values proposed by the manufacturer. The manufacturer cannot adequately model the CF operational and maintenance environments, including any errors that may be introduced by AMMIS such as inconsistent standards of reporting by the various maintenance agencies. However, trend monitoring of MA/FH is valuable because it provides information on the

reliability actually achieved and provides warning of deteriorating situations if it is monitored on a continuous routine basis. The performance trends that can be determined can then be compared to the management targets.

In the forecasting model discussed in Part 6, total maintenance actions (TOT_MA) is taken as the parameter instead of MA/FH so as to give the program the required flexibility for a generic model. Some systems' performance is most meaningful in absolute values, while others are more significant relative to the flying hours. It is a simple matter to convert this parameter to MA/FH. This same principle can be applied to other parameters as well.

c. Total Maintenance Man Hours (TOT_MMH) - Maintenance Man Hours tracking provides visibility of trends in manpower consumption to check and repair the aircraft and selected equipment and systems. Not only are the trends in manpower consumption of interest from a manpower resource planning point of view, but also the reasons for the changes are of interest, especially in deteriorating situations when the scope and depth of repairs are increasing.

The manpower consumption data could be compared for a series of identical maintenance actions. The body of work to be performed is the same every time and, therefore, ideally the maintenance manhours consumed should remain the same. Trends in the change of manpower consumption for the repair work are of great importance. If they are steadily going up, it could be an indication that there is a deterioration in the skill level of the technicians, which could in turn require an

evaluation of the training system. Conversely, if they are going down (say, after a major refit of the fleet), the number of technicians could be reduced. The nature of the repair work is also significant. Both of these scenarios have the potential for providing a very significant impact on the consumption of logistics resources. Also, an increasing repair workload threatens aircraft availability if the workload becomes too large for the established manpower and facilities.

The LSA process carried out during the project definition and implementation phases determines, in part, the maintenance manpower requirements based on a predicted removal rate (which means the isolating and replacing of faulty or failed components) of items from the aircraft. By recording and analyzing the maintenance manhour consumption actually achieved, insight is gained into the adequacy of the maintenance support arrangement relative to the LSAR prediction.

d. Total No-Fault-Found (TOT_NFF) - NFF is the situation where a search for an actual or suspected/potential defect is unsuccessful. There are several reasons for an NFF situation which may not be mutually exclusive:

1. incorrect and/or inappropriate interpretation of symptoms of presumed or actual defects or failures by operators and/or maintainers;
2. faulty diagnosis;
3. incomplete diagnosis;
4. precautionary removals; and
5. ambiguity groups.

The NFF situation consumes manpower and spares unnecessarily. It also loads down special repair facilities (such as the "hush house" or test cell wherein engines can be tested to full throttle) without any beneficial return. It can also undermine the confidence that the operational staff (pilots and flight crew) have in the maintenance staff. Conversely, inappropriate defect symptom reporting by operators undermines the maintainers' confidence in the operational crews for fault recognition. The NFF situation is not only a non-beneficial consumer of logistics resources, but its influence has further disruptive connotations. NFF is, therefore, a prime candidate for monitoring.

It is generally acknowledged that there will probably always be a certain number of NFFs arising. In situations where the diagnostic capabilities limit fault/defect isolation to more than one item (the ambiguity group), the logistics support system must accept the inevitable wasted workload created by the NFF instances.

AMMIS collects NFF data. This is done by the technician who performs the fault/defect diagnosis categorizing the maintenance task as NFF. The NFF occurrence rate can, therefore, be linked directly to any other information resulting from the maintenance action which is also collected by AMMIS such as: the system affected; when; where; how; manhour consumption and aircraft number.

There are two possible causes for the inaccuracy of NFF information. The first cause is the inability of the technician to assign NFF in all instances. This occurs when an item being checked requires a certain set up or calibration which thereby already has removed the possibility of categorizing the instance as NFF. Although

the technician may suspect that a NFF situation exists, he may categorize the maintenance action as "adjusted" or "calibrated" rather than NFF. The technician would probably be reluctant to report that he was "stumped" by the problem and rather looks for a feasible explanation. The second cause is the creation of an illusion of a repair having been made (usually by the replacement of an item, adjustment or calibration) to satisfy the perception of a fault or defect needing to be corrected, even if, in the opinion of the technical staff, there was no technical reason for doing so.

The first cause of possible data contamination noted above, the need for calibration and/or adjustment, can be looked at in an LSM perspective. For example, if, for certain items, the calibration/adjustment rate is high compared to repair by replacement of defective parts, a case could be made to examine the adequacy of the fault/defect symptom interpretation and adjustment/calibration procedures. Each case depends on the technical characteristics of the item under consideration and its maintenance policy. Thus, for certain items or systems, the calibration/adjustment rate may be much more revealing than the NFF rate on its own. The second cause identified above cannot be addressed in the context of LSM.

Despite the possible contamination of NFF data, it is considered suitable for monitoring because the importance of the data and the significance of the trend analysis on it outweighs the minority of cases where the data may be biased or skewed.

e. Total Robs (TOT_ROBS) - The need to rob serviceable parts from unserviceable

aircraft on a sustained basis is one indicator of ineffective supply support. The practice of robbing is frequently debated as to its desirability and overall effectiveness. Nevertheless, robbing is practised because required parts are not otherwise available when required. Therefore, the robbing rate is one measure, among others, of supply support effectiveness. Information on robbing is routinely reported on AMMIS and trend analysis can be performed on this important parameter.

The decision to rob depends on several, often interdependent factors. These include:

1. the availability of a suitable aircraft to rob from;
2. the amount of work involved;
3. the technical risk of inducing further unserviceabilities in the aircraft to be robbed;
4. pressures to render an aircraft serviceable;
5. the expected time lag to receive the required item from the supply system, and
6. different maintenance organizations may not interpret the orders pertaining to robbing in the same way and, therefore, show different rob rates in their maintenance reports (AMMIS inputs).

The requirement to rob demands additional manpower resources. If the need to rob is sufficiently pressing and the frequency of robs is relatively high, there is merit in determining the extra workload associated with this work as additional justification to correct the situation.

Analysis of robs is an important indicator as to the effectiveness of the supply support and of the number of manhours wasted because of the delays incurred between demanding a repair part and obtaining it through the supply system. LSM analysis of the historical occurrences of this parameter should give an indication if a trend is occurring in the rob rate. Identification of this trend would require the maintenance manager to liaise closely with the supply staff to correct the problem before it became critical.

f. Total Failures (TOT_FAIL) - This is a measure of the total number of failures experienced by a particular aircraft fleet (or any other system). It is a "macro" indicator of the overall reliability of the aircraft. Trend analysis on this data would enable the analyst to determine the overall effectiveness of the logistics support provided as well as whether the number is significantly increasing, indicating a requirement for a large scale refit or other major refurbishment of the fleet. The analyst would, of course, have to go into greater detail to determine the actual causes for the failure rate, however, a list of "worst contributors" could be compiled to tell him which sub-systems or assemblies were causing which proportion of the failures.

The foregoing discussion should give an appreciation of the many different considerations and analyses that must take place in evaluating a parameter's suitability for LSM. It should also give an indication of the logical process that must be followed when developing new parameters. Management must ultimately decide which

parameter(s) to select for LSM analysis of different defence systems. The parameters chosen for LSM analysis of a jet engine will undoubtedly be quite different from those selected for analysis of a radio transmitter or for an artillery howitzer. Another key management consideration in selecting parameters will likely be cost. The cost associated with gathering data for various parameters will undoubtedly vary, thus influencing the selection decision.

4.5 An LSM Management Model

Figure 6 An LSM Management Model

Figure 6 represents a management model of the overall LSM system. It is intended primarily to illustrate the interactive role that management has to play relative to LSM. To recapitulate how the system is envisaged, LSM evaluates the effectiveness and efficiency of logistics activities and functions in support of predetermined operational requirements for the user, the maintenance manager. It is implemented by collecting and analysing operational, maintenance and supply data such as that from the AUSR, AMMIS and CFSS respectively and, based on past values, forecasting if and when management goal thresholds or design targets recorded in the LSAR or elsewhere will be exceeded. In the event that deficiencies are identified in the effectiveness of the logistics support package, if deteriorating trends are perceived, or if the cost of logistic support is

determined to be too high, LSM should alert management. Detailed investigation based on the alert would follow. LSM would thus make a significant overall contribution to the successful resolution of the existing or potential problem.

Even though the raw maintenance and supply data required by LSM are historic in nature, the forecasting module of LSM allows that information to be used proactively. The accuracy of the forecast depends on the timeliness, completeness and accuracy of the data, and indeed, on the suitability of the forecasting technique that was selected.

Blocks 1A, 1B and 1C of Figure 6 show the activities which are controlled by current policies and plans and which generate the input data required by LSM (Blocks 2A, 2B and 2C). These data are usually shared among several users. For example, supply data are routinely used in planning for maintenance activities as well as for other typical supply functions such as determining re-order points. The data may also be collected to be used for a variety of purposes other than pure supply or LSM. Gathering maintenance cost histories for audit purposes is one such common use. Changes in policies and plans for these activities may create changes in the rate and type of data that are generated, even though the nature of the data remains unchanged. In the LSM context, the nature of the data is determined by very specific data elements captured by AMMIS, AUSR and CFSS.

Blocks 2A, 2B and 2C represent the specific data required for LSM. They are identified in and extracted from the general body of data that is available. The nature of the data to be extracted is determined by the particular LSM parameters to be implemented.

For the purpose of simplicity, the LSM System diagram (Figure 4) showed that either Block 3 (Management Objectives) or Block 4 (Design Objectives) could be used as baseline values. Both these blocks are interrelated to the degree that ideally the management objective (realistically determined) and the design objective as specified in the LSAR are identical. Practically, however, there will be some differences between the two, differences that LSM should be able to identify.

Block 3 represents the values management desires as ILS objectives for parameters that are capable of being monitored by the LSM system. Typical objectives are planned flying rates, maximum allowable downtime, maintenance manhours per flying hour, supply support satisfaction and any number of others. These management objectives could be influenced by LSAR values (if available), may be based on previous observed performance or may be a baseline that has been statistically calculated. The determination of the degree with which these management objectives are actually achieved, or are expected to be achieved, is a prime functional requirement for LSM. The management objectives must, nevertheless, be reasonable or achievable within the performance characteristics of the equipment or system.

As was discussed above, there may be any number of management objectives which the specified data systems cannot support because they do not contain the relevant data elements. For example, a management objective may be to generate pilots qualified to a predetermined standard within a maximum number of flying hours. The specified data systems do not contain the required data to monitor this. Management objectives relating to the effectiveness of training and simulation also cannot be measured because no data

is collected from these activities on the specified data systems.

Block 4 represents selected information which can be taken from the LSAR, such as MTBFs and MTBRs. These values have significant impact on the design of maintenance policies and plans, as well as long range supply support planning. They are also seminal to ensuring that the management objectives are realistic. Comparison of actual achieved or predicted values against the planning values may provide very useful information about the adequacy of the logistics support package. If a difference exists between management objectives and design objectives, LSM should identify it. However, considering that the system is to be as flexible as possible, the baseline for performance in LSM analysis can come either from Block 3 or Block 4. It is conceivable that an LSM analysis could be run on a particular system first using the management objectives as a baseline and a second analysis could be run using the design objectives from the LSAR. The two outputs could be compared by management to determine if either their objectives or the design objectives require changing.

Block 5 represents the LSM system. It incorporates a specially designed computer database program which accepts selected data from the data collection systems (Blocks 2A, 2B and 2C). This system contains the appropriate algorithms and statistical subroutines to allow a forecast to be made based on the historical data and to compare this forecast with baseline values/management objectives.

Block 6 represents the output of the LSM system. The output may be in the form of a display on a screen, a dump into a separate data file, a printed report, or any combination of these three options. The output is intended to be presented to the

appropriate level of management for their consideration. It cannot be too statistically complex or otherwise complicated lest it be rejected by the designated user.

Block 7 represents the options that exist in management's reaction to the output. This reaction could vary from "no action" to detailed investigation, potentially leading to a number of different kinds of change as shown.

Block 8 ends the process when management decides not to take any action in any of the activities.

Block 9 represents the event when management decides to change operations such as changing flying hours or sortie rates. These changes would subsequently be reflected in the AUSR.

Block 10 represents the management decision to make changes in supply support. The effects of these changes are reflected in the supply support data extracted from the CFSS.

Block 11 represents management's decision to make changes in maintenance policies and plans. The effects of these changes will be reflected in the Maintenance Management Information System (in this case AMMIS) data and subsequently in the applicable LSM parameter.

Block 12 represents management's reaction resulting in the equipment/system design change, which in turn has the potential of changing values in the LSAR (Block 4). For example, the design change may be created specifically for improving reliability and/or maintainability. If the design change is successful, the applicable data fields of the LSAR would be changed to new values and the maintenance plan may be amended. Subsequent

performance is then measured against the new values. Setting new values is not an automated activity, but a deliberate change input in the LSAR under controlled conditions.

Block 13 represents the situation where management's reaction results in changes to management's objectives. These include changes in levels of expectation driven by perceptions that management's earlier objectives were either too high or too low. Objectives which cannot be reasonably attained, based on experience through using LSM, should, therefore, be redefined. Without such redefinition activity, it cannot be determined if the logistics support package is under or over-achieving. Changes in management's objectives are also not done automatically, they too are input manually under controlled conditions and must be realistic in relation to LSAR values.

The management model demonstrates the interrelationship of all the activities associated with LSM. The workhorse is Block 5 where the collation and comparison of the data functions occur for subsequent evaluation by management (Block 7). It is Block 5 which requires further study with regard to its required design considerations.

5. DESIGN CRITERIA FOR AN LSM SYSTEM

As was noted from reviewing the literature, no operational LSM-type system is known to exist at the present time. Before one can be fielded, significant design criteria must be addressed. This section, the focus of the thesis, deals with the design features that are considered to be germane to LSM development, particularly, the importance that forecasting represents to the LSM process. While by no means exhaustive, the following design considerations are seen to be sufficiently general to give guidance in the development of an LSM system.

5.1 Baselines

The first activity of an LSM system would be to monitor the performance of the support system, forecast what trends are developing and relate this performance to baseline values (management goals). The trend information may be used to advise managers if certain aspects of support show improvement, no change or deterioration. For example, a management goal may be that the unscheduled maintenance rate for an aircraft fleet should not exceed a certain value per flying hour. Another example could be that the aircraft downtime for scheduled inspections should not exceed a certain number of working days. These goals would be expressed in terms of baseline values. Baseline values could have several sources; they could come from long term averages observed for the system, the LSAR (if available), values for similar systems, as determined by calculations or values otherwise set by management.

5.2 Alert Levels

Management goals usually originate from planning activity during the project definition and project implementation phases. These management goals (baseline values) may be protected by alert levels which are entered into the LSM system. If alert levels are exceeded, LSM should highlight the parameter thus warning management that a goal is in danger of being violated.

The second main activity generated by an LSM system would concern the reaction that management should take in response to the warnings. An LSM analysis would only give an indication that an alert threshold has been crossed or that one can anticipate that the threshold will be crossed at some specified future time unless corrective measures are taken soon. LSM cannot tell management what to do about the threshold violation. Management's considered response could vary from taking no action at all to conducting an in-depth investigation, depending on the alert level violated, the degree of violation and other information. Results of an investigation, for example, could be the revision of an alert level (threshold), or, indeed, changing the management goal itself.

The setting and monitoring of the appropriateness of alert levels would be a most important activity. That is, one must be confident that an alert trigger is set at an appropriate level. The levels must be practical and sensible. It is not necessarily true that an alert level that is never violated is an indication that all is well. Perhaps the alert level is never violated because it is not at an appropriate value, thus masking a developing problem. In this kind of situation, the inappropriate alert level defeats the purpose of LSM. Conversely, alert levels that are frequently violated when no real problem is

detected could be viewed as a nuisance and could jeopardize the confidence associated with LSM.

Management goals and alert levels should be given the opportunity to mature. This can only be achieved by routinely examining a variety of LSM parameter values. Based on this process, alert levels for parameters may be set, but only when there is confidence that these levels are practical and workable.

The forecasting procedure, which would be central to LSM, must alert the user to conditions which have the potential for becoming unsatisfactory. It must do so with sufficient lead time to allow management to react and correct the situation prior to experiencing the consequences if such a situation were to develop. The LSM forecasting module should, therefore, be structured to intercept the minority of cases which have the potential to cause the majority of the problems.

The four conceivable outcomes that would result from an LSM analysis of a real situation are shown in figure 7

It is apparent that LSM should minimize the occurrence of the two inaccurate readings (those which are underlined) as follows:

LSM RESPONSE	ACTUAL SITUATION	
	NORMAL	UNACCEPTABLE
NO ALERT	DESIRED	ABSENCE OF ALERT
ALERT	FALSE ALERT	DESIRED

Figure 7 Possible LSM Results

- a. **False Alert:** This is a condition by which the LSM output signals a need for adopting corrective measures while the forecast of the parameter value is actually still within acceptable bounds; and

gradually to more sophisticated methods if this is judged to be beneficial and necessary¹⁹. The forecasting model described in Part 6 was designed with this simplicity criteria in mind.

5.6 Example

The following scenario is given as an example of the full cycle of input, processing, output, decision making and action that could be expected in an LSM environment.

Location: 5000 ft over Primrose Lake Weapons Range, near Cold Lake, Alberta.

Time: 0945 hrs, 19 January, 1994.

Aircraft: McDonnell Douglas CF18.

Speed: 500 Knots.

Mission: Practice bombing run with 500 pound practice bombs.

Pilot: "Cold Lake Control, this is Hotel Sierra 5, over"

Control Tower: "Cold Lake Control, go ahead, over"

Pilot: "I'm getting a low power reading on my starboard engine, it's just gone below minimum. It's not responding to throttle. I'm shutting it down now, over"

Control Tower: "Abort mission and return to base"

Upon safely returning to base using the port engine only, the pilot taxis the aircraft to the tarmac. At the maintenance site during the post-flight debrief, he tells the crew

¹⁹Makridakis, Spyros and Steven C. Wheelwright. *Forecasting Methods for Management* 4th ed. New York: John Wiley & Sons, 1985. Page 35.

data to make it statistically significant. LSM can only be useful when the forecast indicates that the sub-system/assembly being monitored reacts to change more slowly than the maintenance organization. Time delays inherent in effecting the necessary changes could conceivably jeopardize proactivity if the threshold is forecasted to be violated soon. In other words, a six month forecast from today would have little validity; therefore, the forecast would have to be back-dated three months (to capture significant data) leaving only a three month forecast to management. With subsequent investigation required to identify the source of the problem, three months may not be sufficient time for management to actually effect the required change.

Fortunately, all Canadian Forces Bases that deal with air operations and maintenance are currently being equipped with Automated Data for Aerospace Maintenance (ADAM) workstations. This real-time system will replace the manually completed input forms and make the raw maintenance data available to the AMMIS system much more rapidly. An LSM system would benefit significantly once ADAM becomes operational. NDHQ directorates that are responsible for the other MMISs are also studying ways to bypass the paper data input stage, having the data collected when the technician enters the particulars on a computer terminal, either by responding to a menu-driven series of questions, or by scanning a series of bar codes that identify him/her (the technician), the system (i.e. the aircraft tail number which uniquely identifies the aircraft and the fleet to which it belongs), the sub-system (such as the jet engine), the module (such as the fuel control unit) and perhaps even the component. Not only will this speed up the data entry process, but it will also significantly reduce the number of input and transcription errors

that presently flaw the manual systems¹⁵. The horizon of forecasts and, therefore, the degree of management proactivity should be able to approach an objective of six months once the input delays are eliminated.

The AUSR currently collects information about flying operations, flying rates, fuel consumption and statistics on the number of serviceable and unserviceable aircraft on strength for each squadron and base. The data is locally collected and manually manipulated. It is sent to NDHQ as a formatted message once a month and is considered to be completely accurate for the preceding month. Those parameters that use AUSR data are, therefore, constrained with this one month delay, which is, nevertheless, considerably more attractive than the three month delay for old (non ADAM) AMMIS data.

Finally, the CFSS is a near real-time on-line ADP system. Files are updated very quickly as supply items are issued and other transactions (such as restocking) occur. The limitation here is the access that LSM could have to the data. CFSS hardware resources would have to be dedicated to extract and transfer the required data from the CFSS to LSM. Those responsible for developing the next generation CFSS system (known as the CFSS Upgrade project) acknowledge that they have an obligation to interface their data with the MMISs¹⁶. An LSM-type system would conveniently provide this bridge.

For the purpose of designing an LSM system, the input data from the various sources

¹⁵Project Manager for Equipment Systems Management briefing to the Director General of Communications and Electronics Engineering and Maintenance, NDHQ, Ottawa, 2 February 1990.

¹⁶Col R.B. Morris, CFSS Upgrade Project Manager briefing to the Association of Data Professional Services and Software Organizations, Ottawa, 16 January 1990.

has to be confidently considered as being accurate. This presumes that there are no "disgruntled employees" or others having a vexatious intent to corrupt or distort the system. While the system should be capable of dealing with innocently entered mistakes as part of the random error, large scale deliberate input errors would totally invalidate the output.

The speed with which LSM could respond to its inputs will depend on the hardware, software and management structure put in place for it. The speed with which proactive intervention could take place will depend on how quickly management can react to the LSM output. If the reaction is not timely, LSM will identify when and where management intervention should have taken place rather than monitor the success of the intervention that was based on its warnings.

5.3.1 Characteristics of the Input Data Series

a. Seasonality - The forecasting module used by LSM will have to account for the fact that external factors influencing the use of the equipment vary according to cyclical patterns. The baseline value will, therefore, have to be adjusted by a seasonality factor to reflect this cyclical pattern.

Again using an aircraft as an example of a defence system, the equipment is subjected to temperature variations which follow a 12 month cycle. These temperature variations require different servicing routines and maintenance actions to prepare the aircraft for use. Additionally, the number of hours that the equipment is used often follows a 12 month cycle; personnel regulate their activities such as leave and courses in this cycle and major

operational exercises are generally scheduled in an annual cycle. For instance, the CT114 Tutor jet trainer aircraft used by 431 Air Demonstration Squadron, the "Snowbirds", are used intensively from May until September each year giving aerial performances across North America. Less intensive training activity, and, therefore, aircraft usage, occurs during the fall, winter and spring while the squadron members practice their routines for the coming demonstration season. The aircraft are used only slightly during the Christmas and New Year period when many of the pilots and ground crew take annual leave and the squadron adopts a minimum manning posture. It would, therefore, be logical and important to give due consideration to a seasonal period of 12 months in the forecasting module of the LSM system.

b. Characteristics - In Part 4, six representative parameters dealing with the performance of logistics support for aircraft defence systems were discussed. Prior to what is learned from monitoring, little is known about the specific behavior (pattern) of the respective data series from which these parameters are determined. Despite this lack of knowledge, the need for developing the forecasting module for an LSM system will require making some important assumptions which are based on a subjective assessment of the characteristics expected for these data series. These assumed characteristics are as follow:

1. the data display univariate time series properties. This means that the historical data relating to a single parameter to be forecast is sufficient for detecting the basic time pattern and extrapolating it to forecast the future;
2. the forecasting model must handle non-stationarity. Non-stationarity specifies that

the process mean changes over time;

3. there is a seasonality factor with a period of 12 (months);
4. the time horizon of the forecasting is medium, which means less than two years and typically six months;
5. at most, five years of reliable data (from the maintenance management information systems, the supply system and operations data bases) is available on a monthly basis; and
6. the errors are normally distributed.

These assumptions are considered to be reasonable for the purposes of designing the forecasting module for an LSM system.

5.4 LSM Output

The output reports from an LSM analysis should be suitable for quick interpretation by management. The output should also reach management sufficiently early to give the users time to react and organize changes that may be required in the logistics support system to avoid situations which threaten operational availability or the logistics support budget. Care must be taken not to overload managers with information they cannot use. It should be recalled that one of the main objectives of LSM was to free management from the tedious burden of sifting through, and trying to draw information from, the reams of printouts with which they are now burdened. The LSM output information must be relevant and to the point.

WSMs and LCMMs are generally responsible for a large number of items and wish

to deal only with those that may present a problem. For instance, an LCMM could be responsible for several avionics systems for a particular fleet of aircraft. He usually only has time to deal with the small percentage that are currently presenting a problem. Reports concerning the large percentage that are operating satisfactorily are only cursorily reviewed. Their use of LSM would, therefore, consist principally of problem areas identified in "exception reports".

Considering that LSM should be able to meet the requirements of all levels of management, it should have the ability to be tailored. For example, LSM could be programmed to prepare a "macro" report for senior management who are not concerned with the day-to-day status of individual systems or equipment, but rather who are interested in overall effectiveness. Senior management may only be concerned with the parameter "successful sortie rate" of a particular fleet (type) of aircraft compared to the goals they had set for that fleet. LSM would then simply query the AUSR database for the number of successful sorties reported and compare it to the number planned. If the fleet maintains its objectives, it may be concluded by management that the logistics support for that fleet is adequate. This information would be of value to senior management; however, it would provide no information about resource consumption or trends in resource consumption required to maintain the objective. That information must be gleaned by different LSM analyses.

In the detailed or "micro" extreme, a Life Cycle Materiel Manager may be interested expressly in the parameter "total number of maintenance manhours per flying hour" that are expended in maintaining a particular engine compared to what the manufacturer

claimed. He would expect LSM to give him the information required so that he could determine if the training of the technicians was correct or whether the manufacturer's reliability estimates were unreasonable.

What this is intended to show is that LSM output should be able to take many forms and should be able to be expressed in many different levels of detail.

WSMs and LCMMs have within their terms of reference the latitude needed to remedy organizational and technical deficiencies which limit the defence system from effectively accomplishing its mission. Many of these managers, while experts in their own right, are unfamiliar with anything more than basic statistics. This means that the reports generated by the LSM forecasting program must be readily understandable regarding trend interpretation on the parameters they select. These managers can then investigate the reason(s) for any forecast of unsatisfactory performance to determine the best corrective measures to take. The statistical concepts behind the formulation and the processing of the forecast should be transparent to the user. A "goodness of fit" or other similar indicator should be sufficient for the manager to determine how much confidence he can place in the forecast.

The number of parameters that are required for LSM analysis will vary with the particular defence system program and the preferences of the manager. As the program matures and more is learned about critical areas of ILS resource consumption, different parameters may be seen to be of significance. The LSM output should be able to summarize these parameters for a specific item or system in the form of a printout report, a data file, an output to a computer screen or any combination of these. The data file

should be formatted in such a way that it could be imported into programs such as Lotus 1-2-3 or other sophisticated graphics programs in order to prepare graphical presentations for senior management. The most common form of LSM output, however, should be a simple printout (including a basic graph) that is generated when a baseline or management goal has been, or is forecasted to be, violated. The graph should show the actual performance (in terms of the selected parameter), the forecast, the baseline and highlight when the violation can be expected to occur. An additional feature should be that a report should be able to be requested at any time, even in the absence of an alert condition, simply to show how the system is performing in terms of a selected parameter.

For demonstration purposes, six parameters representative of performance and trends relating to the support of military aircraft have been selected for detailed description in the prototype model presented in Part 6: Flying-Hours, Total Maintenance Actions, Total Maintenance Man-Hours, Total No Fault Found, Total Robs and Total Failures. The example output is shown in terms of Total Maintenance Man-Hours; however, it could equally be presented in terms of any other defined parameter.

5.4.1 Worst Contributors¹⁷

A management rule of thumb is that ten percent of the problems require ninety percent of management's effort to solve. The other ninety percent of the problems either solve themselves or require minimal management intervention. Management can,

¹⁷ The term "worst contributors" is widely used in the maintenance communities of the Canadian Forces. It means that the identified systems, due to their poor performance are the greatest contributors to the unexpected expenditure of ILS resources.

therefore, assume that certain systems will demand much more of the ILS effort than will others. Also some systems are much more critical from an operations or safety point of view. Therefore, corrective action aimed at certain systems and equipment are likely to have a greater payback than will corrective action in other areas. LSM should identify those systems/equipment where logistics resources are most beneficially expended. While this feature is not included in the prototype model, a basic LSM design feature should be to highlight worst contributor information in the output. This would typically be accomplished by listing the equipment or sub-assemblies that are causing most of the problems in descending order for the selected LSM parameter analysis of the system. For example, the LSM output on a Maintenance Action per Flying Hour (MA/FH) parameter analysis for the GE 404 jet engine (two of which are used to power each of the 130 CF 18 fighters), should indicate not only the historical values of this parameter (and its forecast values), but also should indicate that the three worst contributors to that parameter over the past six months had been, say:

- a. compressor adjustment - 27% (32 incidents);
- b. fuel control unit replacement - 14% (15 incidents); and
- c. afterburner valve replacement - 12% (13 incidents).

The remaining 49% of maintenance actions would have been an assortment of miscellaneous repairs/adjustments having no apparent pattern.

LSM should provide information not only on the effectiveness of the ILS program, but should also be able to identify which equipment/systems consume a greater proportion of ILS resources than planned. The worst contributors are those most responsible for

unplanned ILS resource consumption and should, therefore, be the focus of attention by management.

5.4.2 Follow-On Investigations

LSM parameters will typically be reviewed regularly, however, there may be instances where additional information is required to investigate the reasons for the behaviour of the parameters. For example, a regularly monitored set of parameters may show a steady increase in the downtime of aircraft undergoing scheduled maintenance and along with this is a proportionally increasing expenditure of the technicians' time. This in turn would generate the requirement to investigate the reasons for these phenomena and more information would be required. It should, therefore, be possible to extract information on an ad-hoc basis in the hope of finding clues for the increasing downtime and manpower consumption. It is possible that the reasons may not be found by further analysis of the data. In this case, the analyst will not find the information or may be driven to erroneous conclusions. Here, the reasons for the deteriorating trends may be:

- a. increasing numbers of failure and defects are discovered during the scheduled maintenance;
- b. specialized forms of repair are required, such as composite material repair or special welding techniques;
- c. a decreasing number of properly trained staff;
- d. changes in the working environment;
- e. increasing numbers of field performed modifications or special inspections which

are all performed during the scheduled maintenance period;

f. unavailability of support equipment.

If the only source of information to the user/analyst is the AMMIS database, he may conclude that the reasons are a. and e. and perhaps certain repairs from b. LSM analysis of the AMMIS data would not reveal information relating to causes c., d. and f. since it does not collect the required data. Cross referring to a manpower database could conceivably give some insight to cause c., however, a database management system that could access and interchange information from a wide variety of data banks such as this is probably still several years away.

Ad-hoc extractions of data to investigate the reasons for an unacceptable parameter value are useful, but only when it is known that the information that is being sought is represented by the data in the data system being interrogated. Without such reasonable assurance, the analyst may draw false conclusions and may pursue a useless, if not counterproductive, line of investigation.

It must be remembered that the principal reason for an LSM system is to monitor and not to investigate, although investigation may result from cues provided in the monitoring process. Investigations may include ad-hoc enquiry into other data systems, however, the ad-hoc enquiry capability of the LSM system should initially be limited to the data which has been transferred to LSM for the basic monitoring purposes.

5.5 Selection of a Forecasting Technique

The forecasting module (or component) of an LSM system will be the key to

proactivity. It is, after all, the forecast of how the logistics support of the defence system will perform in the future that enables management to plan and implement the changes required to that logistics support. In the characteristics of the data presented earlier, it was assumed that the data pertaining to the defence system's logistics performance had time series properties. There could be other inherent patterns to the data such as geographical (temperature/altitude) or operational (equipment held in reserve or used for active training). However, for the sake of simplicity, time series models are seen to be the best general method to describe most of the circumstances that could affect the data. With the large number of forecasting techniques available, it is necessary to go through a number of steps in selecting the best model¹⁸:

- a. state the period for which forecasts are required;
- b. state the degree of accuracy that is required in terms of mean squared error (MSE), mean absolute percentage error (MAPE), or another measure to indicate how well the model fits the data;
- c. from the data collected, designate a portion of them (usually the most recent) as hold-out data to test/validate the model;
- d. determine if there is a trend (linear, exponential, etc);
- e. if there is no trend, employ a moving average or single exponential smoothing technique on the data to determine the best fit. The forecast thus generated should then be compared with the hold-out data and also against a naïve forecast to

¹⁸Summarized from a discussion with (and notes from) Professor Clem Hobbs, School of Business, Carleton University, 15 August, 1989

- determine if the required accuracy has been achieved. If the accuracy is acceptable, the model can be used, but only to forecast one period ahead;
- f. if a seasonal pattern is suspected, algebraically remove the trend and subject the data to an autocorrelation test to determine the seasonality frequency;
 - g. assuming that seasonality is present, experiment with several techniques such as seasonal decomposition into an additive or multiplicative model, Winter's seasonal model, Fourier series or others and test each one against the hold-out data to determine which one gives the best results; and
 - h. refinements such as tracking signal correctors could be added later if it is determined that they are necessary.

It should be noted that steps d through g require the intervention of a forecasting specialist. He must interpret the results and judge whether the forecasting method is reasonable and reliable. Step h implies that continuous monitoring of the forecasting method is required. The forecasting specialist must ensure that the models are still applicable (the forecasting results are still within acceptable error limits), and if not, he must design and test alternative models, abandoning the current one. This forecasting specialist has a vital role to play in the creation of an accurate forecasting method for LSM. His continuous monitoring of the forecast model will ensure that the results are not in error due to inappropriate modelling.

Significantly, it has been established by experienced forecasters that it is much wiser to apply a straightforward and simple forecasting approach initially and then to upgrade

gradually to more sophisticated methods if this is judged to be beneficial and necessary¹⁹. The forecasting model described in Part 6 was designed with this simplicity criteria in mind.

5.6 Example

The following scenario is given as an example of the full cycle of input, processing, output, decision making and action that could be expected in an LSM environment.

Location: 5000 ft over Primrose Lake Weapons Range, near Cold Lake, Alberta.

Time: 0945 hrs, 19 January, 1994.

Aircraft: McDonnell Douglas CF18.

Speed: 500 Knots.

Mission: Practice bombing run with 500 pound practice bombs.

Pilot: "Cold Lake Control, this is Hotel Sierra 5, over"

Control Tower: "Cold Lake Control, go ahead, over"

Pilot: "I'm getting a low power reading on my starboard engine, it's just gone below minimum. It's not responding to throttle. I'm shutting it down now, over"

Control Tower: "Abort mission and return to base"

Upon safely returning to base using the port engine only, the pilot taxis the aircraft to the tarmac. At the maintenance site during the post-flight debrief, he tells the crew

¹⁹Makridakis, Spyros and Steven C. Wheelwright. *Forecasting Methods for Management* 4th ed. New York: John Wiley & Sons, 1985. Page 35.

chief that the starboard engine was running erratically early in the flight, then the RPMs gradually decreased. The crew chief calls for the duty aero engine technician and briefs him on the symptoms experienced during the flight as detailed by the pilot on the "On-Aircraft Maintenance" record sheet, which, when opened, is the work order for mandatory repair action. The technician performs his diagnostics and isolates the fault to the Fuel Control Unit (FCU) of the right engine which he then removes. The technician takes the faulty FCU along with its historical records and a copy of the "Off-Aircraft Maintenance" work order, which was the authority for its installation, to the supply section where he demands a replacement FCU from the duty supply technician. After installing the new (or overhauled) FCU, the technician performs the other mandatory inspections that are necessary to close out the work ticket. The crew chief enters the details of the maintenance action just performed on the maintenance shop computer terminal, accessing the Automated Data for Aircraft Maintenance (ADAM) system. Aircraft tail number, squadron owning the aircraft, hours of flight on the airframe, where failure was discovered (in-flight, before flight inspection or at second line/base maintenance facility; in this case, in-flight), effect of failure (mission partially completed, mission completed or mission aborted; in this case, mission aborted), statement of failure, statement of rectification and verification (here, FCU replacement), manpower consumption (total number of hours expended by all technicians), time in, amount of time to identify the problem, replacement parts used (or any parts that he may have had to order since there were none held in the supply section; not applicable in this case), time out information and identification codes of the technicians verifying the aircraft's airworthiness are all

entered into the menu-fed program.

That evening the data for the day's transactions are automatically dumped from the base ADAM system to the IBM mainframe computer at Data Center Ottawa where they are added to history in the AMMIS database.

Two days later, the mainframe receives its weekly preprogrammed instruction to send a copy of all AMMIS data to the LSM mini computer at DAS Eng in the Rockliffe site of CFB Ottawa. The LCMM for the GE 404 jet engine has a standing request that LSM analysis of that engine be performed on a weekly basis in terms of what he has determined to be the most revealing parameter, Maintenance Actions per Flying Hour (MA/FH). The LSM analysis proceeds automatically to collate the number of maintenance actions reported on the fleet of GE 404 engines from the AMMIS database with the number of flying hours for the CF18 (the only aircraft on inventory that uses the 404) that have been reported on the monthly AUSR. LSM also automatically queries the CFSS database for all GE 404 engine components requested. LSM then proceeds to calculate the plot of MA/FH values for the past 24 months and invokes the forecast subroutine to perform a six month statistical forecast based on the past 24 data points, considering their seasonal variation. LSM calls up the LSAR data for the 404 engine. The LSAR holds baseline information and contains information such as what the expected number of MA/FH should be for that family of aircraft. LSM compares this baseline value to the actual performance and its forecast and notes that there has been a steady increase in the number of MA/FH over the past six months. Although the alert level threshold (which has been selected by the LCMM to be one standard deviation above the

baseline) has not yet been reached, the forecast indicates it will be violated in two months if the trend continues. This triggers the report generation subroutine and an alert report (which includes a plot of the MA/FH values and their forecast) addressed to the LCMM is run off the line printer. The printout concludes with the list of the sub systems and components which have contributed most to the number of MA/FH over the past 24 months, the "worst contributors".

The next morning, the LCMM receives his mail and studies the LSM alert report he has just received. He sees that the trend is deteriorating and notes that the engine FCU is at the top of the list of worst contributors. After doing preliminary investigation (which could vary from performing another LSM run on a related parameter to phoning an expert technician at one of CF18 squadrons to corroborate the report) he decides that the LSM analysis and forecast are valid and sets out to find the cause of the problem. He starts by calling the LSM duty operator and asks him to query the LSM database in relation to CFSS data for the consumption of FCUs for the different bases from which the CF18s operate: Baden Baden, West Germany; Bagotville, Quebec; and Cold Lake, Alberta. The reply comes back that Cold Lake is consuming twice the number of FCUs as the other two bases. The LCMM knows that the number of aircraft at all three bases is roughly the same, their environments are similar, they fly approximately the same number of hours and the same type of missions every month. He then calls the Supply Manager for the FCUs and has him determine which batches are in which location. The Supply Manager queries the CFSS database and determines that Cold Lake took delivery of 100 Lot 1234A FCUs manufactured by Ace Pumps eight months ago and that 20 were still

in stock. Bagotville had taken delivery of 50 Lot 2466B manufactured by Beta Pumps two months ago and had 45 in stock. Baden Baden had 60 Lot 1786C manufactured by Delta Pumps last month and still had 55 in stock.

The Supply Manager passes this information on to the LCMM who then calls his contact at the prime contractor, McDonnell Douglas Aircraft in St. Louis, Missouri. He is told that there have been several complaints from the US Navy (who fly the F18 Hornet, very similar to the CF18) concerning FCUs. He asks if they happened to be manufactured by Ace Pumps and further if they were from Lot 1234A. The reply is that most were indeed from Ace in Lots ranging from 1000 to 2000.

The LCMM now decides that he has found the likely source of the problem and proceeds to send a message to Cold Lake recommending they quarantine the remaining Ace FCUs. He orders a replenishment shipment of 50 new fuel pumps (stressing they must be any brand except Ace) be sent to Cold Lake from the central warehouse in Edmonton. He also sends out an advisory message to the other CF18 bases to have them check their stock to ensure they have no Ace FCUs. Finally, he issues a Special Inspection (SI) leaflet to all CF18 bases recommending the inspection of all aircraft for the Ace FCUs and performing a precautionary replacement on all found.

When the time comes to solicit bids for replenishment stocks of fuel pumps, the LCMM will remember the incident and will be very particular in recommending who he thinks should get the contract. Ace pumps will probably not be high on his list. The LCMM also writes up this case for publication in the next Maintenance Analysis Digest which is sent to the maintenance sections of all flying bases and air force technical

schools. The technician who performed the replacement of the FCU in Cold Lake thus reads about the situation concerning the FCUs and sees that his participation has contributed to the overall solution to a potentially catastrophic problem. The digest provides the feedback to the field that is so necessary to demonstrate to the technicians that their efforts in compiling the data are worthwhile and indeed essential to the harmonious operation of the whole maintenance organization.

This example is expected to be typical of the full cycle of proactive maintenance management that should exist once LSM has become operational in the Canadian Forces.

6. A PROTOTYPE LSM FORECASTING MODEL

A preliminary prototype LSM forecasting model has been developed by collaborating with the Directorates of Aerospace Support Engineering and Logistics Analysis of NDHQ. The objective of the model is to demonstrate many of the concepts described in this thesis and, in particular, to produce a representative output report.

6.1 Model Description

While this model is spartan, makes general assumptions and is not rigorous it is, nevertheless, presented as a demonstration of the LSM concept and gives the reader the opportunity to study an example output report similar to what a future refined LSM process can be expected to produce.

The forecast program was written in the FORTRAN language and was compiled to run on an IBM or compatible PC having a minimum of 512 KB of RAM. The input consists of historical maintenance data from AMMIS that has been formatted in terms of the parameters Flying Hours (FH), Total Maintenance Actions (TOT_MA), Total Maintenance Manhours (TOT_MMH), Total No-Fault-Found (TOT_NFF), Total Robs (TOT_ROBS) and Total Failures (TOT_FAIL) for a representative fleet of aircraft. The historical maintenance data then forms the basis for a statistical forecast which can then be studied.

The ideal LSM process as conceptualized in this thesis consists of automatically drawing raw data from a variety of sources (i.e. AMMIS for maintenance, CFSS for

supply and AUSR for operational data), formatting that data in terms of parameters, comparing them to the LSAR or some other baseline, forecasting future performance in accordance with the criteria cited earlier, and reporting worrisome trends to management.

This preliminary prototype, however, has been designed to process only samples of AMMIS (or other MMIS) data that have already been formatted in terms of the parameter to be studied and have been manually transcribed into the LSM database; the program cannot read data from other input sources (CFSS, AUSR). If an LSAR or other baseline is not given, one is calculated using the arbitrary criteria that 95% of the historical values are set below, and 5% set above, the baseline which has had the seasonal adjustment incorporated. Future performance is forecast using autoregression²⁰, that is, the forecast of the parameter value is related to previous values of itself at varying time lags (the only independent variable considered) and gauges the output in terms of alert levels that, again, have been arbitrarily selected. Autoregression is assumed to be a suitable forecasting method for the data even though the procedures outlined in Part 5.5, "Selection of a Forecasting Technique" have not been entirely followed. The program produces the output report regardless if an alert is detected or not. Future refinements to the program may determine that other forecasting methods should be used.

The ease of use of the program allows the user to insert other baseline or alert level values and he need not have more than a rudimentary knowledge of statistics to interpret the results. Moreover, the complexity of even the most basic forecasting technique is

²⁰This technique of autoregression is discussed in detail in Makridakis, Spyros and Steven C. Wheelwright, *Interactive Forecasting: Univariate and Multivariate Methods*, 2 ed. San Francisco: Holden-Day Inc. 1978. Page 370.

transparent to the user; he is not required to select a particular forecasting method based on the characteristics of the data; the generic time-series autoregression proceeds automatically. *It must be understood that the intent of the program is not to give WSMs and LCMMs a fully operational LSM system. Rather, they are encouraged to experiment with a working prototype using data they have available for the systems for which they are responsible. They can also establish their own baseline/alert level criteria. In this manner, they should become familiar with the concept of LSM and appreciate how it will help them perform their duties. In the final analysis, it is their acceptance or rejection of the concept that will determine whether further development of LSM will proceed.*

Appendix C depicts the introductory screens that are generated when the program is run and Appendix D contains further detail on the program particulars.

6.2 LSM Forecast Program Application Example

The CF116, commonly referred to as the CF5 Freedom Fighter, was manufactured in Canada in the mid 1960s by CANADAIR Limited of Montreal. It is a twin engine jet fighter aircraft that is having its role changed to that of an advanced jet trainer to prepare pilots at Canadian Forces Base Cold Lake, Alberta to fly the CF18.

In order to demonstrate a typical run of the LSM forecasting program for the CF5 fleet (which totals approximately 100 aircraft), AMMIS data (sorted in terms of the Total Manhours parameter) have been manually extracted and transcribed into the format which the program can read. The historical data from June 1982 to May 1987 are time expired from a security point of view and they are, therefore, unclassified. Despite the fact that

these data are quite dated, they are, nevertheless, perfectly suitable to demonstrate the principles of the program.

What follows is an actual output report of the program, called FORECAST. A brief explanation of the output is then given.

Time series forecast for equipment CF116 parameter TOT_MHRS

Observation period starting Jun 82 and ending May 87

Forecast period from Jun 87 to Nov 87

Baseline value : 13771.880 (estimated)

Mean of observed values : 9924.767

Standard deviation : 2345.802

Seasonalized baselines

Jan : 15620.030 Feb : 14439.030 Mar : 14268.830 Apr : 13948.550
 May : 14334.740 Jun : 13179.970 Jul : 12776.910 Aug : 13910.000
 Sep : 13899.110 Oct : 13170.640 Nov : 14482.480 Dec : 11232.300

Last 12 observations

		Date	S. baselines
1	9158.800	Jun 86	13179.970
2	10644.700	Jul 86	12776.910
3	10791.800	Aug 86	13910.000
4	12025.000	Sep 86	13899.110
5	11933.800	Oct 86	13170.640
6	10031.500	Nov 86	14482.480
7	8464.800	Dec 86	11232.300
8	12431.300	Jan 87	15620.030
9	10167.300	Feb 87	14439.030
10	11275.700	Mar 87	14268.830
11	8798.600	Apr 87	13948.550
12	9412.900	May 87	14334.740

					Probability of alert code			
	Date	Prediction	S. bas.		0	1	2	3
1	Jun 87	11908.090	13179.970	*	.726	.229	.043	.003
2	Jul 87	13410.780	12776.910		.381	* .413	.179	.028
3	Aug 87	12608.780	13910.000	*	.731	.225	.041	.003
4	Sep 87	12908.650	13899.110	*	.682	.261	.053	.004
5	Oct 87	12721.760	13170.640	*	.585	.322	.085	.008
6	Nov 87	12193.990	14482.480	*	.861	.124	.014	.000

(* indicates the alert status of the predicted value.)

Quality of fit indicator : .13 (A value of 1.00 is optimal)

GRAPH

SCALE : 1 space = 1431.0460 units

Legend : ! = baseline B = seasonalized baseline

o = observation * = prediction

\$ = B and o or B and * superimposed

This output report indicates that summarized AMMIS "Total Manhours" per month parameter data has been used from June 82 to May 87 and that a six month forecast is generated to November 87. A baseline (such as an LSAR value) has not been given, therefore one has been calculated (13771.880) so that 95 percent of the historical values are below it. This is calculated using a constant times the standard deviation and adding the mean. By changing the values of the constant, the baseline can be adjusted so that, say, 90% or 99% of the values are below it.

The baseline has had the monthly seasonalization factors applied and these are given under "Seasonalized baselines". The program then lists the last 12 observations giving the AMMIS and the seasonalized baseline values. The prediction section follows whereby the forecast for the six month period (determined by the time-lag autoregression) is shown as, again, is the seasonalized baseline. The probabilities of these forecast values crossing the alert code thresholds are then given. Explanation of alert codes is given in Appendix D. In this example, it can be seen that a level 1 alert can be expected in July 87. Any time the probability of alert level 0 is less than .500, alert level 1, 2 or 3 is triggered.

The confidence that can be placed in the forecast is given by the quality of fit indicator, R_a^2 , the adjusted coefficient of multiple determination. In this example it is .13, meaning that the ratio of the explained variation of the model to the total variation is not very good from a model fitting point of view; the correlation between the historical data and the forecast is poor. This could be due to outliers in the data that have not been rejected by personnel who screen raw data before inputting them into AMMIS. Because the autoregression is based on the least squares method, the presence of outliers induces

a significant pull on the model fitting curve. Another possible explanation for the poor fit could be that new conditions have been imposed on the system. For example, the CF5 is changing from a Fighter Ground Attack (FGA) role to advanced trainer beginning in the summer of 1987. This means that several different systems were removed from the aircraft and others were installed, activities which consume a considerable number of manhours (the parameter under study) and which could not be predicted by the model.

Finally, the graph depicts much of the above data. The prediction point for July 87 falls to the right of the baseline value, thereby triggering the alert. This means that the model forecasts that, based on the historical data, more manhours will be expended in that month maintaining the fleet of CF5 aircraft than anticipated. The value for October 87 also comes close to the baseline and might also prompt further investigation.

A "User's Manual" has not been prepared for the FORECAST program. Rather, a series of introductory screens are invoked on first running the program. These screens (reproduced in Appendix C) should give the user all the information necessary to run and use the program.

In order to use this program for other systems, the maintenance manager (LCMM) must extract the maintenance information from the respective MMIS in terms of the parameter he wishes to study. He must determine whether there is a baseline value which he wishes to input, or if he is satisfied with the criteria that 5% (or 10% or 1%) of the values are greater than the baseline. These settings are fed into the program by the LSM analyst. The maintenance manager can then use the program to see a forecast of how the parameter can be expected to perform in the future if no changes are made and the

cyclical pattern repeats itself.

The forecasting module is but one component in the overall LSM process, however, it is the key to giving management the ability to anticipate where problems are developing.

This example of an LSM output report demonstrates brevity, clarity and succinctness. As can be expected using real data, the results are not ideal. Nevertheless, the objective has been met. Using this model, LCMMs would have a tool where none existed before. They can experiment with the system and become more familiar with it. Even in applications that indicate low confidence levels, the system acts as a flag raiser and the user can chose whether or not to take action and conduct further investigation based on the report. As Professor Benjamin Blanchard from Virginia Polytechnical Institute, an outspoken advocate of ILS and exploitation of technology recently noted, analytical methods must be employed throughout the life cycle of systems/products to retain the competitive edge of North American industry, be it defence or consumer product related. Data that is collected during the design phase should not be shelved once production has begun. It should be continually updated during the in-service phase to provide the insight necessary to optimize the system/product's performance. Computer aided tools must be employed to interpret that data and allow for that optimization to take place²¹. LSM is seen to have the potential to become one such important computer based tool.

²¹Professor Benjamin Blanchard in his address to the Canadian Society of Reliability Engineers (Ottawa Branch), 27 March, 1990.

7. CONCLUSION

7.1 Contributions of the Study

The objectives of this thesis have been to introduce the concepts of ILS as they relate to LSM and to discuss several critical design criteria that are central to the development of an operational LSM system.

ILS elements were discussed and four were selected as being suitable for LSM analysis. The principles of parameter determination and an explanation of the development of six of them was intended to demonstrate how diverse areas of interest by logisticians and management alike could be addressed by LSM through the manipulation of data elements that are captured by current information systems, or could be captured by systems now under development. It was noted that the accuracy of the input data is tantamount to an effective LSM system.

The management model demonstrates the many considerations that influence LSM, and the prototype shows that it is feasible to use maintenance data proactively once a suitable forecast algorithm has been established. The detailed example of the full cycle of activity in a maintenance environment that includes LSM shows the considerable potential that it has in aiding management in the provision of the most cost effective and optimal support for defence systems. With the ability to quickly analyze what appear to be isolated problems, identify a trend and raise a flag warning of potential problems through LSM, management would have a tool that would give them the potential not only to reduce costs, but it would also give the operational personnel an increased margin of

safety while operating highly complex and dangerous weapon systems.

Giving this LSM process a higher profile and making more maintenance managers aware of both it and its potential is seen as being one major contribution of this thesis. The other is to have provided some general guidance as to what to consider in developing an operational LSM system.

7.2 Limitations and Assumptions

Before the concept of LSM can be fully implemented, it must be noted that data integration problems exist. Data management is central to the concept of LSM since it is necessary to have data in a form that can be readily accessed in order to perform the statistical analysis and generate the forecast regarding the adequacy of the ILS program. In order for this to occur, existing databases must be rationalized and interfaced.

Operational "real-world" databases such as the Canadian Forces Supply System, various Maintenance Management Information Systems, Utilization Reports and others are not compatible with the LSA™ prediction data or, for that matter, with each other. As has been noted, several database upgrade projects are currently underway in the Canadian Forces and the degree of their "interoperability" with one another is one area being studied. The Data Reconciliation/Resolution initiative at NDHQ is currently addressing the problem. As well, data integration and data sharing between different systems are objectives the NDHQ Integrated ADP System (IAS) project expects to resolve within the next five years. Optimism has been expressed by key participants in these

initiatives concerning the eventual success of the objective of integrating the databases.²²

Notwithstanding that these problems are very real and current, they go beyond the scope and purpose of this study. It is acknowledged that a comprehensive LSM system can only be implemented once the "interoperability" of the databases has been achieved. As was seen with the LSM forecasting model prototype, actual data was extracted from the AMMIS database in order for it to be read by the computer program. The eventual objective is to have the envisioned LSM system extract the data automatically. Fully automated performance monitoring of logistics support, as would be possible with LSM, can only proceed once the data sharing and integration of the source databases has been achieved.

In the Abstract and the Introduction, it was stated that LSM could be "equally applicable to the commercial transportation sector and equipment intensive industry". In order to concentrate on the military application with its emphasis on monitoring the effectiveness of logistics support, neither of those applications have been pursued. It is assumed that the non-military reader will intuitively appreciate how an analogous LSM system could be applied to the private sector. All that is really necessary is a historical database of observed performance in terms of management selected parameters and management approved baseline values. An LSM-type program then compares the two and alerts management if problems can be expected in terms of those selected parameters. An LSM system allows support management staff to anticipate potential problems and to

²² Colonel R.B. Morris, Project Director for the Canadian Forces Supply System Upgrade Project, 26 July 1988.

take corrective measures proactively.

The one assumption that is elementary to LSM is that there will be no appreciable change in the operation or use of the equipment being analyzed. Any statistical forecast of future performance presumes that usage will remain much as it has been. Any significant change will result in unreliable forecasts for many of the parameters that require the seasonal usage cycle as the foundation for their forecasts. If, for example, the entire fleet of CF18 aircraft were deployed to the Middle East for high intensity operations rather than the normal operational training and NORAD/NATO air defence role in Canada and North West Europe, a new start point for analysis would have to occur with that deployment; forecasts based on previous usage would simply not be acceptable.

7.3 Potential Impediments

The major impediment that could exist to the future implementation of an LSM system is the reluctance that has been expressed by some decision makers concerning the further development of the concept. It is perceived by some that further research into LSM is not warranted at this time because of the inadequacies of existing Maintenance Management Information Systems. The MMISs are indeed burdened with inefficient data gathering methods and their use is seen as being voluntary by some, resulting in a lack of credibility of several output reports, particularly the simple linear forecasts or trend analyses, that they are now capable of producing. It is a well known fact that some middle level managers, for example, judge the performance of their maintenance sections by the number of (hand-completed) MMIS input forms that are returned as being

incomplete, illegible, in obvious error or otherwise deemed unacceptable by the MMIS input sections. They feel that the efficiency of these maintenance sections is directly correlated to this return rate. It does not take a maintenance shop supervisor long to conclude that the easiest way to reduce the number of returns (and, therefore, increase his perceived efficiency rating) is by reducing the total number of input forms submitted, regardless that there has been no corresponding reduction in the number of maintenance tasks actually performed. This situation can be further exacerbated since not all headquarters maintenance managers insist that sections report all maintenance actions to the MMISs as they are supposed to. This may be due to previous dissatisfaction with the system, a lackadaisical attitude or a desire not to be seen as being intrusive. Consequently, there are justifiable credibility gaps in the information.

The new generation of MMISs being planned will address many of these concerns. For example, an MMIS authorization code for each maintenance task could be necessary to draw repair parts from the closely controlled supply sections. Another possibility is that an MMIS code is necessary for each technician to justify his time spent on a job, the sum of which would be compared to the total time he was available in a specified period. While these measures could be seen as being "Big Brother" and draconian by some, they will go a long way to ensuring accurate and timely input data, and in conjunction with more "user friendly" input systems, they will give the MMISs the credibility they require to be the impetus for the development of LSM. The fundamental human foible of resistance to change can only be overcome by education and the demonstrated advantages that will be gained by the individual using the new, or changed, system; making his job

easier, safer, and less prone to the high-tension, top priority emergency calls that all technicians have learned to fear. Adequate funding, personnel and other resources necessary for full LSM development should proceed now so that it will be ready once the upgraded MMISs have been declared as being operational.

7.4 Future Directions

LSM is still in the early prototype mode. The concept has been demonstrated and is seen as being feasible, however, further research on a number of aspects of the system are required before a fully functional model can be fielded.

The requirement to improve on the statistical algorithm of the FORECAST program is one primary area. The prototype was not intended to be rigorous, rather, it was intended to give a relatively easy to understand start point to statisticians and programmers, who in concert with MMIS experts, would build on it to develop a functional system. The statistical methodology recommended in Section 5.5, Selecting a Forecasting Technique, could assist future developers in this task.

The parameters required to address the specific requirements of management are another area where considerable potential for development exist. Some maintenance managers might more readily accept LSM if a customized parameter that he sees as being important is developed for him.

The list of "worst contributors" to a detected or forecasted problem has been mentioned but not demonstrated. This is an area where a great deal of potential exists since the analyst is given a number of suspect areas in order of priority for the cause of

a problem instead of only one. As it stands at the present time, an LSM analysis might indicate that sub-assembly X is causing 33% of the failures to a defence system and the maintenance manager corrects the fault with X only to find that sub-assembly Y, which had been contributing 32% of the problems was not picked up by LSM and he now has to correct its fault. With the worst contributors listing, he could have conceivably corrected both concurrently and, more importantly, could have investigated possible relationships between them.

The ability to interact with other databases was one area that was identified. Future database structures can be expected to facilitate interoperability, a feature that could be exploited by LSM. The prototype identifies the AUSR, AMMIS and CFSS as the "real world" databases feeding LSM. Having access to any number of other databases relating to ILS would augment LSM. For example, a database relating to the training of technicians could be used in evaluating the effectiveness of their training relative to an increasing number of repeat maintenance actions of one kind. It could then be determined that more training is required in that particular procedure.

The need for accurate input data was often emphasized in this thesis. Some degree of automation is being achieved in the aircraft weapon system data input domain with the introduction of the ADAM workstations, but the technician is still required to transcribe the raw data onto the ADAM terminal, a process that is subject to errors. Having certain edits incorporated into a "smart" terminal could reduce the number of errors. If the technician enters an incorrect Equipment Application Code (EAC) number, for example, the terminal should, by cross referring to a database of valid EACs, alert the technician

to this fact. Other environments which should expect to use LSM such as Army, Navy and Communications and Electronics defence systems should similarly improve their data collection methods. The use of bar codes was one suggestion to reduce the number of input errors.

After an initial operational LSM system has been fielded, there are several exciting modifications that could be incorporated using emerging technologies. For example, incorporating an Expert System with LSM could be instrumental in building up a corporate memory of maintenance actions for different defence systems. LSM would identify those sub-systems, assemblies and components that are most prone to failure (the worst contributors) and the Expert System could identify the diagnostics and preventive or corrective maintenance actions that should be performed to correct the problem. The maintenance manager using this enhanced LSM system would be in a position to not only identify the greatest consumer of ILS resources, but he would also be able to order maintenance units to take specific preventive (proactive) measures. To carry this concept even further, it is conceivable that a proven and reliable LSM/Expert System terminal could be located at each maintenance facility. The technician giving his input (to ADAM, for instance), could benefit from all the corporate data that has been collected for the specific system he is working on. After identifying the system, the terminal (which would be networked with the main LSM system) could guide him in the other preventive maintenance actions which should be performed.

Finally, it is interesting to note that at least two Project Offices in NDHQ which have major defence system projects under development, the New Shipborne Aircraft (NSA) and

Canadian Patrol Frigate (CPF), are actively advocating the development of LSM. While neither of these systems will be introduced into service until the mid to late 1990s, those involved perceive that many, if not all, of the problems identified above will have been resolved and they want LSM ready to provide them the information they will require at the time their defence systems become operational.

The Directorate of Maritime Engineering Support (DMES), for example, intends to have a functioning LSM system ready for the introduction into service of the new frigates. In order to have a cadre of LSM knowledgeable and trained Naval engineers at that time, DMES is sponsoring post graduate studies specializing in LSM (and its ancillary areas of interest such as ILS and LSA) in the faculty of Engineering Management at the Royal Military College of Canada commencing in the fall of 1990.

APPENDIX A

AN OVERVIEW OF **INTEGRATED LOGISTICS SUPPORT AND LOGISTICS SUPPORT ANALYSIS**

Integrated Logistics Support

Integrated Logistics Support is viewed as the composite of all considerations necessary to assure the effective and economical support of a system throughout its programmed life cycle. The elements, or key activities, which have the most impact upon ILS are as follow:²³

1. Maintenance Plan
2. Supply Support
3. Support and Test Equipment
4. Packaging, Handling and Storage
5. Transportation
6. Technical Data
7. Facilities
8. Personnel
9. Training and Training Devices
10. Quality Assurance
11. Computer and Communications Resources
12. Logistic Support Management Information

²³ Much of this information was acquired during attendance at the DND ILS/LSA course in November, 1988.

1. Maintenance Plan: This includes all planning and analysis associated with the establishment of requirements of the overall support of a system throughout its life cycle. It begins with the development of the maintenance concept and continues through the accomplishment of LSA during design and development, the procurement and acquisition of support items, and through the consumer use phase. It includes the designation of resource requirements and their estimated rates of consumption. It is accomplished to integrate the other facets of support.

2. Supply Support: This includes all spares (units, assemblies, sub assemblies, modules and components), repair parts, consumables and special supplies needed to support prime mission oriented equipment, software, test and support equipment, transportation and handling equipment, training equipment, and facilities. It also covers provisioning documentation, procurement functions, warehousing, distribution of material and the personnel associated with the acquisition and maintenance of spare/repair part inventories at all support locations.

3. Support and Test Equipment: The identification of, planning for, and implementation of the plans for all the equipment required to perform the support function except that which is an integral part of the mission equipment itself. It includes ground handling and maintenance equipment, all tools, metrology and calibration equipment, all test equipment for on and off system maintenance as well as the computer software associated with the test equipment.

4. Packaging, Handling and Storage: The definition of the requirements, resources and procedures necessary to ensure that all systems, equipment and support material are stored, preserved, packaged and handled in a manner which will make them available for use in a specified condition.

5. Transportation: The identification of the transportability characteristics, the means of transportation and the transport limits and restrictions of all material and personnel involved in the logistic/maintenance process.

6. Technical Data: The identification and acquisition of the information describing the engineering and logistics characteristics which must be known to operate, maintain and support the system/equipment in a prescribed condition and manner. Technical data includes research and engineering data including reliability and maintainability data, engineering drawings and associated lists, specifications, standards, process sheets, manuals, technical reports, catalog item identification and related information. Also included is computer documentation such as flow charts, programmer's and user's manuals and development and product specifications. The computer software, however, is not considered to be technical data.

7. Facilities: This category refers to all specific facilities needed for system operation and the performance of logistic/maintenance functions. Physical plant, real estate, environmental impact, maintenance shops, warehousing, and calibration shops are to be

considered .

8. Personnel: The identification of, planning for, and implementation of the plans for the manpower requirements, personnel assignments and training required for the most efficient and economical logistics support of the defence system/equipment during its complete in-service life. Personnel requirements are identified in terms of quantity and skill level for each operation and maintenance function by level and geographic location.

9. Training and Training Devices: The identification of, planning for, and implementation of the plans for the type, level and location of the training, and the qualifications and number of instructors, computer-aided training programs, technical manuals in both official languages, training aids and equipment resources required for the training of personnel throughout the in-service life of the defence system/equipment. This includes initial training and refresher training.

10. Quality Assurance: The activities and functions concerned with and necessary for providing adequate confidence that a product or service will meet the user's needs. Such activities will include analysis of requirements and specifications, evaluation of tenders, verification of contractor control of quality with respect to design, development production and testing and determination of quality control/inspection requirements.

11. Computer and Communications Resources Support: The identification of, planning

for and implementation of the plans for the computer and communications resources required for mission and logistics support. It does not include the computers which are integral to the defence system/equipment, nor does it include the CF Supply System and Maintenance Management Information Systems. The resources include the facilities, hardware, software and manpower.

12. Logistic Support Management Information: The management of all information generated for or used by both DND and the contractor in planning for and implementing the other elements of ILS. The information will include, but not be limited to, the LSAR, comparative data on operational systems, trade-off studies and associated data and cost, schedule and control information.

Logistics Support Analysis

If ILS is the concept, then LSA provides the tools/techniques to implement the concept. LSA is identified as being the key activity in any ILS program. LSA is not a single analysis but rather is a series of interlocking analyses, studies, reports, etc. all of which contribute to the ultimate goal of identifying the logistic support required to operate and maintain a defence system/equipment under given operational and maintenance concepts. It is much easier and more cost effective for logistic considerations to be incorporated into a design than to try to have the same changes made when the system is in the production stage. For example, it has been estimated that every dollar spent towards incorporating logistic supportability in the design would require the expenditure

of \$1000 to achieve the same result in the in-service stage.

The U.S. Department of Defense Military Standard, MIL-STD-1388-1A, defines LSA as "the selective application of scientific and engineering efforts undertaken during the acquisition process, as part of the system engineering and design process, to assist in complying with supportability and other ILS objectives".

The same MIL-STD identifies fifteen main logistics tasks and sixty-five sub-tasks related to the development of the identification of the logistic support package for a system. Data is extracted from the results of these tasks and is entered into the LSAR and the LSAR database management system allows for the LSAR data to be manipulated in the form needed by the user.

The tasks within MIL-STD-1388-1A are broken down into the following distinct Task Sections:

1. **Task Section 100 - Program Planning and Control.** The purpose of this task section is to provide for formal LSA program planning and review actions.
2. **Task Section 200 - Mission and Support System Definitions.** This task section is to establish supportability objectives and supportability related design goals, thresholds and constraints through comparison with existing systems and analysis of supportability, readiness and cost drivers.
3. **Task Section 300 - Preparation and Evaluation of Alternatives.** This task section is to optimize the support system for the new item and to develop a system

which achieves the best balance between cost, schedule performance and supportability.

4. Task Section 400 - Determination of Logistic Support Resource Requirements.

This task section is used to identify the logistic support resource requirements of the new system in its operational environment and to develop plans for post production support.

5. Task Section 500 - Supportability Assessment. This task section is used to ensure that specified requirements are achieved and deficiencies corrected.

It must be decided early on which sub-systems, assemblies, etc. LSA is to be done. LSA on the entire defence system would be very expensive. In this regard it is normal to do LSA on a "maintenance significant item" which is defined as "an item which, by its application or inherent characteristics, can be expected to fail or require replacement during normal operation or maintenance of the end item".

The LSA process focuses initially on engineering design considerations - the relationship between the design of the equipment and the design of the logistics support. This early design is done in industry with some essential inputs, such as the concept of operations being provided by the customer (i.e. DND). During equipment design and development, much work is done in the area of Reliability and Maintainability Engineering, the results of which have a very significant bearing on the in-service support

that is required.

The driving force behind the need for logistics support, and thus for LSA, is the occurrence of equipment failure. One must predict the modes of failure, the effect of each failure mode on the equipment and the criticality of failure of the equipment to the success of the mission. This study is one of the key tools in LSA and is called Failure Modes, Effects and Criticality Analysis (FMECA); it provides information that is essential for the rest of LSA. It is included in the MIL-STD-1388-1A tasks as are the other analyses that will be briefly mentioned. It begins with a determination of which sub-systems should be fully analyzed and which could be assessed using a less rigorous process. Once the sub-systems that have been selected for FMECA have been identified, it starts at the lowest level in an equipment breakdown structure and works upward. It is very labour intensive and is, therefore, very expensive.

The most critical failures must be prevented or be minimized. The next tool thus concerns the necessary preventive maintenance program. This is developed using an analytical process called Reliability Centered Maintenance (RCM). In RCM analysis, one asks a series of questions about the consequences of failure; the questions are posed in the order given by a logic flow diagram. The objective is to determine a minimum acceptable set of preventive maintenance actions. Further actions should be avoided since they increase support costs while providing little or no benefit and may even make matters worse by inducing failures.

Those failures which are not prevented must be corrected. All preventive and corrective maintenance actions are addressed in the Maintenance Task Analysis (MTA).

Each maintenance task is identified and the skills needed to do the task are determined. The inventory of required skills is then used to assess the adequacy of current trade structures and to plan a technician training program. Also, for each task, the resources required to perform the task are listed. These include tools, test equipment, spare parts, support equipment, technical manuals, etc. An estimate of repair time, given the necessary skills and resources, is made. This analysis determines what logistics support is needed.

MTA indicates what skills and resources are needed, but not where to locate them and what quantity to obtain. This is determined by the Level of Repair Analysis (LORA). For example, one could concentrate all of the maintenance resources at the servicing level, or alternatively, one could just remove and replace failed "line replaceable units" (LRUs) there and repair the LRUs at a contractor's plant. In between, one must consider the role of repair shops, regional repair centres, etc. Some of the many alternatives can be eliminated because they are in conflict with the basic concepts or principles regarding operations and support. In LORA one determines the most economical mix and distribution of logistics support given an initial set of feasible alternatives. It is common practice to do a rough LORA before doing an MTA.

Since LORA is a form of economic analysis, it provides an estimate of the cost of maintaining a defence system. This information can be combined in a Life Cycle Cost (LCC) model with capital acquisition and other costs to determine the cost of buying, operating and supporting the defence system. The accuracy of the LCC estimate will depend on the accuracy of the technical input data to the model and this will change as

design and development of the system progresses. LCC can be used to identify "cost drivers" which can then be studied separately to minimize costs. The question that should be asked is: What can be done to reduce the cost of ownership while maintaining equipment performance and quality of support? Any resulting design changes will necessitate a reiteration of any affected part of the LSA process.

There are other tools in the LSA process such as Sparing Analysis to determine the optimum quantity and distribution of spare parts considering a given budget and/or availability target. Maintenance Plans generated through LORA are an essential input to sparing analysis, and similarly the cost of spare parts is a necessary input to LORA. Additional aspects of LSA consider transportability, support during war time conditions, the impact of changing technology, etc.

All the data that are generated by the above LSA processes are gathered in the LSA Record (LSAR) as specified in MIL-STD-1388-2A. The LSAR is a series of data sheets which provide a standard format for systematically developing, recording, processing, storing and reporting elements of LSA data. The important point is that the LSAR should not be discarded once the defence system has been acquired. It is an invaluable source of a large quantity of quality data that should continue to be used (appropriately updated by renewed selective LSA analyses as changes are incorporated in, or planned for the equipment/system) during the total life cycle of the equipment/system.

follow-on version of the program.

The main program, FORECAST, is used as an umbrella for five major modules: GETSERIES, BASISTAT, PREDICT, GENALERT and DETAILS. Figure 8 outlines the algorithm of the program.

Figure 8 The LSM Forecast Program Algorithm

Main Program

The main program performs the following operations:

- a. Initialize the month names and the default data file name, currently set to

11. Robs per Flying Hour
12. Rob Man-Hours per Flying Hour
13. Mean Time Between Confirmed Failures
14. Mean Maintenance Man-Hours to Repair
15. Mean Downtime (1st Level)
16. Base Repair Fraction
17. No Fault Found
18. Pre-Installation Failures
19. Mean Time Between Precautionary Removals
20. Turn Around Time (2nd Level)
21. Turn Around Time (3rd Level)
22. Incidence of Repeat Snags
23. NORS Rate (Not Operationally Ready - Supply)
24. Customer Satisfaction Rate
25. Fill Rate
26. Immediate Operational Requirement (IOR) per Flying Hour
27. Immediate Operational Requirement (IOR) Duration
28. Scrap Rate
29. % Life Lost

APPENDIX C

LSM FORECAST PROGRAM INTRODUCTORY SCREENS

The LSM FORECAST program has five introductory screens that summarize what the program does. These screens are invoked on loading the program and, most importantly, highlight the significance of alert levels. In the last screen, the user indicates his preference for a particular output for the results of the analysis.

Screen 1

LOGISTICS SUPPORT
MONITORING
FORECAST PROGRAM

DEVELOPED BY MAJ. A. ARÈS AND MAJ. P. LUDORF

Strike any key when ready

Screen 2

THIS PROGRAM IS DESIGNED TO DEMONSTRATE THE PRINCIPLES OF LOGISTICS SUPPORT MONITORING. BY ANALYZING HISTORICAL AMMIS DATA ON A PARTICULAR PARAMETER, A FORECAST IS GENERATED. THIS FORECAST IS COMPARED TO A BASELINE VALUE SUCH AS FROM THE LSAR, FROM DETERMINED NORMS, OR AS GIVEN BY MANAGEMENT GOALS. IF NO BASELINE IS GIVEN, ONE WILL BE CALCULATED BASED ON MOVING AVERAGES OF PAST PERFORMANCE PLUS A FACTOR TO ACCOUNT FOR SEASONALIZED VARIATIONS.

NOTE: THE CONFIDENCE THAT ONE CAN PLACE IN THE FORECAST DECREASES AS THE PREDICTION HORIZON INCREASES.

Strike any key when ready

Screen 3

THE BASELINE IS SEASONALLY ADJUSTED WITH THE ASSUMPTION THAT THE SEASONAL PATTERN IS STABLE, THAT THERE ARE 12 MONTHS IN A COMPLETE SEASONAL CYCLE, AND THAT THE SEASONAL ADJUSTMENTS FOR THE LENGTH OF THE COMPLETE CYCLE SUM TO ZERO.

THE OUTPUT GRAPH SHOWS IF THE FORECAST PROGRAM EXPECTS AN ALERT TO BE TRIGGERED AT SOME FUTURE TIME BASED ON THE TRENDS IDENTIFIED IN PAST PERFORMANCE. AN ALERT IS DEFINED AS OCCURRING WHEN THE FORECASTED VALUE IS ONE OR MORE STANDARD DEVIATIONS REMOVED FROM THE BASELINE VALUE AS FOLLOWS:

Strike any key when ready

Screen 4

	BASELINE	1 STD DEVIATION	2 STD DEVIATIONS
prediction is less than or equal to the baseline	I	I	I
	I	I	I
	I	I	I
	I	I	I
ALERT 0--^	I	I	I
		I	I
		I	I
ALERT 1-----^		I	I
			I
			I
ALERT 2-----^			I
			I
			I
ALERT 3-----^			I

THE HIGHER THE ALERT LEVEL, THE HIGHER THE PROBABILITY OF A PROBLEM BEING FORECAST FOR THAT PARTICULAR PARAMETER.

Strike any key when ready

Screen 5

Select letter corresponding to choice of output desired:

- (S)creen only for all output - default.
- (F)ile - and screen as well - for all output.
- (D)ata file for transfer to LOTUS 1-2-3.
- (P)rint content of file upon completion;
all output will scroll on screen and
be recorded into file prior to printing.
- (C)hoose method of output for each parameter.
- (Q)uit this session - exit the system.

Enter your choice?

APPENDIX D

SYNOPSIS OF LSM FORECAST PROGRAM

Program Overview

In order to demonstrate the feasibility of the LSM concept, a computer program had to be developed which could read input maintenance data, compare it to a baseline value (such as that given in the LSAR, or mathematically determine a baseline), perform a forecast based on the data and generate an alert if the baseline is or is expected to be exceeded.

The LSM FORECAST program was subsequently developed as a first attempt at prototyping such a demonstration model. It was written principally by staff from the Directorate of Logistics Analysis of NDHQ in collaboration with the members of the LSM project team. It consists of some 1100 lines of FORTRAN code compiled under Microsoft_{TM} Fortran V to run on an IBM or equivalent personal computer. It incorporates several sub routines from the commercial statistical software package, IMSL_{TM}. The FORTRAN programming language was used because of its superior characteristics in dealing with scientific and technical applications and the relative ease with which the IMSL sub-routines could be incorporated into the program.

As was noted in Part 6, the procedures outlined in Part 5.5, Selecting a Forecasting Technique, were not rigorously applied for the purpose of prototype development. However, a critical investigation of the suggested technique would be crucial for any

follow-on version of the program.

The main program, FORECAST, is used as an umbrella for five major modules: GETSERIES, BASISTAT, PREDICT, GENALERT and DETAILS. Figure 8 outlines the algorithm of the program.

Figure 8 The LSM Forecast Program Algorithm

Main Program

The main program performs the following operations:

- a. Initialize the month names and the default data file name, currently set to

"forecast.dat". The latter is used in b.

b. Open the file named "fcstfil.dat". This file contains the names of all the data files to be processed in this run. If the file "fcstfil.dat" is not available, the program will process the default file named in a. If neither file can be located, the program stops.

c. Open the first data file mentioned in "fcstfil.dat" or the default file, as applicable.

d. Call GETSERIES, to read in the first series and attendant information. Should there be errors in the data that render forecasting impossible, declare so and proceed to step i.

e. Call BASISTAT, to compute basic statistics.

f. Call PREDICT, to forecast future values.

g. Call GENALERT, to determine the alert levels, the alert status of the predictions, and the first alert code reached.

h. Print out the results of the forecast: "Alert code (1,2 or 3) will be reached at month y", or else "No alert code will be reached". Ask the user if a detailed printout is desired. If so, call DETAILS.

i. Read the remainder of the data file, until a star (*) is reached, or else the end of the file. If a star is found at the beginning of a line, it marks the start of new data. Proceed to d. (see "How to create data files" for additional detail). If the end of the file is reached, proceed to j.

j. Close the data file. Read, from "fctstfil.dat", the name of the next data file to process, and go to c. If there are none left, or if the default file name was used, terminate the program.

GETSERIES

This module, or subroutine, gathers the required AMMIS data available from the current data file that has been formatted in terms of the selected LSM parameter.

a. Read the equipment and parameter names.

b. Read the number of predictions desired, the safe direction from the baseline, and the date of the first observation (see "How to create data files" for details).

c. Read the baseline value.

d. Read the number of observations. If this is greater than 24, proceed to e. Otherwise, notify the user that at least 24 data points are required, signal to the main

program that the forecast must be aborted, and return.

e. Read the observations, one per line, for as many lines as are indicated by the value read in d. Return.

BASISTAT

This subprogram computes basic statistics for the series; an important part of the subroutine is the generation of the seasonal adjustments²⁴.

a. Compute the mean and standard deviation of the observed series.

b. If the baseline value that was read in is zero (i.e. was not given), this means the program must estimate it. In this case, the baseline value will be chosen so that 95% of the observations fall on the safe side of the baseline. This percentage determines a factor called BETA, which is obtained from a normal distribution table (we assume that the observations are normally distributed). The estimated baseline is calculated to be $MEAN - UP * BETA * STDEV$, where UP is +1 if the safe side of the baseline is above it, -1 otherwise. If the 95% value is found to give too many false alerts or too few actual alerts, the value could be modified through trial and error until a more appropriate one is found.

²⁴ Kendall, M., A. Stuart, and J.K. Ord., *The Advanced Theory of Statistics, Vol3, Design and Analysis and Time Series*. New York: MacMilan, 1983. Page 487

c. The seasonality must then be extracted from the series. The BASISTAT module makes the monthly seasonal adjustments to the seasonalized baseline. The purpose here is to account for the historical variations to the parameter that are usually known to maintenance personnel. This is done so as to minimize false alerts due to those known variations. The technique used comes from Kendall, Stuart and Ord. Assuming that the seasonality pattern is stable, the moving average of 12 (months) is first centered (since there are an even number of months) before computing the monthly seasonal adjustments. The residuals for each month are measured about their mean, yielding the monthly seasonal adjustment. Since they are considered as additive seasonal factors, they are then added to the baseline value in order to obtain the seasonalized baseline as follows:

d. Obtain the "12-month centered moving average" of the original observations. This is an array whose i th element is $\{ \text{SERIES}(i) + 2*\text{SERIES}(i+1) + 2*\text{SERIES}(i+2) + \dots + 2*\text{SERIES}(i+11) + \text{SERIES}(i+12) \} / 24$

1. Obtain the array RESID by subtracting the moving average from the original array.

2. Compute the average residual for each month, and derive the difference between the monthly mean residuals and the overall residual mean. This gives the seasonal adjustments.

e. Once the seasonality is obtained, add the baseline to it to obtain the BASESEAS array, which contains the seasonalized baselines. Note that the array elements are ordered

from month 1 to month 12, month 1 being the starting month of the time series, not necessarily January.

f. Lastly, compute the rank of the first month of prediction. Note that the monthly seasonalized baselines are the initial threshold value (Alert Level 0) used to determine the alert status of the predicted values (see GENALERT).

PREDICT

This is the module which performs the forecast function. The operations permit flexibility in fitting the best prediction model without user interaction. The need to generate a forecast in the absence of a variety of independent variables has required D Log A analysts to develop an unconventional method based on the work of Makridakis and Wheelwright. Autoregression, the basis of the forecast, uses time and seasonality alone as the independent factors applied to time series data²⁵.

- a. Remove linear trend from the series
- b. Compute the autocorrelation
- c. Build the matrix of lagged explanatory variables

²⁵ Much of the theory discussed above derives from Makridakis, Spyros, and Steven C. Wheelwright, *Forecasting Methods for Management*. New York: John Wiley & Sons, 1985.

d. Perform the time series autoregression on the 3 most significant autocorrelation values

e. Reinsert the linear trend

f. Compute the predicted values and the standard deviation for each prediction

g. Compute the adjusted coefficient of multiple determination, R_a^2 , as the measure of how well the model represents the actual data²⁶

GENALERT

This subroutine computes the alert levels and determines the unseasonalized alert levels and the alert status of the predicted values. A simple formula is used to determine alert levels. Any predicted value that is less than or equal to the baseline is on alert status 0. A forecast that is above the baseline by no more than one standard deviation means alert level 1. Exceeding the baseline by more than one but less than two standard deviations yields alert level 2. Finally, a predicted value that is more than two standard deviations from the baseline results in alert level 3. "Screen 4" shown in Appendix C gives a graphical representation of the alert level criteria.

²⁶ Neter, John, William Wasserman and Michael H. Kutner *Applied Linear Regression Models*. Homewood, Illinois: Richard D. Irwin Inc, 1983. Page 241.

- a. First, ALERT(O) is the baseline value.
- b. Second, ALERT(1) is $\text{BASELINE} + \text{STDEV}$, where STDEV is the standard deviation of the time series, computed in BASISTAT. We assume here that UP = -1, for simplicity. Likewise, ALERT(2) is $\text{BASELINE} + 2 * \text{STDEV}$.
- c. Once this has been calculated, examine each predicted value, starting from the last one. Compare it to the ALERT array, to which has been added the seasonal adjustment corresponding to the current month.
- d. The alert status is determined by checking if the value is above ALERT(O) (which means alert code 1 or more), then if it is above ALERT(1) (alert code 2 or 3), then if it exceeds ALERT(2) (and thus is alert code 3).
- e. If a predicted value is alert code 1 or more, it is identified by ALERTCODE and ALERTDATE. As we progress backwards (meaning that the oldest data is read first and the newest data is read last), the earliest alert code greater than zero will be the one that is noted.

DETAILS

The last major subroutine produces, or "prints" the detailed output (which can be sent to an ASCII data file, a LOTUS data file, directly to the printer or to the screen only) of

the information that the program has processed. It includes a table giving the probabilities that the normally distributed prediction falls within alert levels 0, 1, 2, or 3. An asterix indicates the zone where there is a 50 percent or greater cumulative probability that the prediction itself will fall.

- a. Print the names of the equipment and the parameter.
- b. Print the observation and forecast periods, as in "From May 84 to July 87".
- c. Print the baseline, the mean and the standard deviation.
- d. Print the seasonalized baselines, from January to December.
- e. Print the last 6 observations.
- f. Print the forecasts, together with a table giving the probability, for each forecast, that it lies in a given alert interval. That is, inform the user that, for example, the third prediction has a 90% chance of being an alert code 0, a 7% chance of alert code 1, and a 3% chance of alert code 2. This makes the forecast quality clearer.
- g. Finally, print a graph of the data, using the subroutine GRAPH.

GRAPH

This last subroutine prints a graph of part of the data.

a. It determines the graph's scale, that is, the interval between the highest and lowest values to plot, so as to fill the space available.

b. It then proceeds to plot the baseline, seasonalized baselines, last 6 observations, and forecasts.

c. Flourishes include dates in the margin, and a scale of parameter values, to the nearest convenient unit (from 0.1 to 1000).

HOW TO CREATE DATA FILES

1. A data file for the forecasting system must follow this format:

data file name	example
"equipment" "parameter"	"CF116" "TOT_NFF"
<npred> <up> <month> <year>	13 -1 6 82
<baseline>	0
<length>	60
<obs1>	98

<obs2>	38
...	
<lastobs>	104
*	*

Within this data file, each successive data set is entered following the delimiter(*) by repeating the format above.

Where:

"equipment": is the name of the equipment being studied. The length of the string may not exceed 15 characters. The string is delimited by quotation marks (").

"parameter": is the name of the parameter observed. It may not be longer than 8 characters. The string is delimited by quotation marks (").

<npred>: is the number of predictions desired in terms of months away from the last available observation. Realistically, this value should not exceed 12. The farther away a predicted value is from the last known observation, the less significant it becomes.

<up>: indicates which side of the baseline is "safe". That is, whether

parameter values should be higher than the baseline (as in the case of availability) or lower (as in the case of repair actions performed). If values should stay higher than the baseline, <up> must set to +1. Otherwise, it must be set to -1.

<month>: this is the month number of the first observation. January is 1, December is 12.

<year>: this is the year of the first observation. It must have only two digits.

<baseline>: this is the baseline value. If it is unknown, .. value of zero may be written. This will make the program estimate the baseline from the rest of the data.

<length>: this is the number of observations in the time series. It must be at least 24, and no more than 120.

<obs>: are the observations (data). There can only be one to a line.

*: follows the last observation. It is used to separate data sets, as it is possible to have more than one parameter series per file.

2. Should the user wish to perform predictions with a smaller number of observations than are actually in the file, there is no need to delete the extraneous values. By simply decreasing the value of <length>, the program will stop before the last observation is reached. It will then scan to find an asterisk (*) before beginning a new data set.

3. If data formatted as above is contained in a single file, that file should be named "forecast.dat", the default given by the program. Should there be several files available all containing similarly formatted information, it is possible to process these data files in one run. In such cases a file must be created and given the name "fcstfil.dat" and contain, on separate lines, the names of all the data files to be used by the program.

fcstfil.dat

data file name 1

data file name 2 ...

data file name n

4. The program has a pre-specified file searching pattern. Priority is to first look for the file "fcstfil.dat" and process all the files specified within (obviously, these files must be accessible). If "fcstfil.dat" can not be found, it will next look for the file named "forecast.dat" which must contain the required data sets. If neither of these two file names can be found, the program will abort.

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