UAV Logistics for Life-Cycle Management 108

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Abstract

Although an Unmanned Aerial Vehicle (UAV) does not require a crew onboard, it is a kind of flying platform, which requires nearly the same logistics support similar to the most manned aircraft. UAV system is a system of the systems. Thus, UAV logistics support should cover the required support for all subsystems of the UAV system including unmanned aircraft and, ground control station.

UAV logistics support system depends on many different parameters including the type of the UAV system, its operational requirements, and its operational environment. It should be a system with a reduced logistic footprint, enabling a fast deployment and high mobility.

Because of urgent operational requirement for the UAVs, traditional UAV design procedures weren't followed, and first prototypes were deployed for operations without enough consideration for logistics. So, mishap rate and sustainment cost of the initial UAVs was very high because of insufficient logistic consideration during design phase. Immature UAV systems have required many modernizations and upgrades.

UAV logistics support system depends on many different parameters including the type of the UAV system, its operational requirements, and its operational environment. For a small hand-launched UAV system, relatively little logistics support is required, while larger UAV systems mostly need more logistics support.

UAV logistics support should be considered during every phases of the life cycle. Logistics support efforts should be proactive to predict the possible problems before they become serious issues.

The goal of this chapter is to provide the reader with general knowledge on UAV Logistics for Life-Cycle Management with the logistics challenges faced by the UAV pioneers and the possible future UAV logistics trends which improve UAV employment.

108.1 Introduction

Although a UAV does not require a crew onboard, it is a kind of flying platform, which requires nearly the same logistics support similar to the most manned aircraft. Improving the overall efficiency and readiness of UAV systems for all purposes, including military, civil, and commercial employments, is critical. A well-established and operated logistics system serves to increase the efficiency and readiness of the UAV system while decreasing the acquisition and sustainment costs for customers.

UAV system is a system of the systems. The employment the UAV system requires the contribution of each subsystem. One small failure or problem for a subsystem of the UAV system may impede the overall success of the operation at a certain level or completely stops the system. Thus, UAV logistics support should cover the required support for all subsystems of the UAV system including unmanned aircraft and ground control station.

UAV logistics support system depends on many different parameters including the type of the UAV system, its operational requirements, and its operational environment. It should be a system with a reduced logistic footprint, enabling a fast deployment and high mobility.

In a traditional acquisition, a system would be designed to meet certain requirements, and then a prototype would be built and tested before production of the operational vehicle. But, under some circumstances, the need to field a functional system may be greater than the need for a system that meets all requirements. According to a RAND Report [1] this has been the case for some current UAVs, whose prototype vehicles were quickly pressed into actual service, even as the overall production process was being accelerated; test, evaluation, and real-world operations were taking place concurrently. USAF UAS Flight Plan [2] states that the lack of any substantive logistics planning during acquisition has resulted in large contractor logistics support (CLS) expenditures, postproduction engineering studies, and modifications that could have been mitigated with a more rigorous approach.

Lessons learned during operational employment of the UAVs have been applied to later versions of such UAVs. So, mishap rate and sustainment cost of the later version UAVs have been decreased to reasonable numbers. Although there has been some important progress, this problem still exists for the newly developed UAVs in many countries. On the other hand, retrofits and upgrades created many different versions/blocks of the same UAV while creating different logistics support packages (mostly spares) for the same fleet of the UAV.

UAV operations resemble those of manned aircraft in many ways. The similarities include aerial platforms, professional personnel, use of airspace, requirement for aviation logistics support, and training. Although a UAV does not require a crew onboard, it is piloted or directed by a pilot or an operator from a ground or airborne control station. Thus, a UAV is a kind of flying platform, which requires nearly the same logistics support similar to the most manned aircraft.

For logisticians, basic support for UAV systems is the same as for manned aircraft. However, there are some fundamental differences between manned and unmanned systems that affect the UAV logistics support system. Here are some important characteristics that are unique for UAV systems:

- Critical importance of ground systems and payloads.
- Complicated system availability tracking because of the role many different subsystems.
- Fault isolation is more complex, requiring robust onboard diagnostics.

These unique characteristics and associated implications require a different approach than that of manned platforms in some areas of life-cycle management, especially when engaged in requirements generation, systems engineering, product support planning, and management [2].

For a small hand-launched UAV system, relatively little logistics support is required, while larger UAV systems mostly need more logistics support. Like manned aircraft, UAV systems require dedicated logistical support, which includes the equipment to deploy, transport, launch, enable communications, and sustain the UAV system according to U.S. Army UAS Roadmap [3].

Since UAVs have only been employed by armed forces with quite a few examples of civilian and experimental UAV usages so far, UAV logistics support section is mainly based on military sources. But, UAV logistics support procedures, which are explained in this chapter, would be adapted to civil and commercial UAV employments that are expected to expend in mid-term future.

108.2 Logistics Principles

UAV systems require a logistics approach similar to manned aircraft. According to U.S. Marine Corps MCWP 3-21.2 Aviation Logistics document [4], the logistics planners and the entities responsible for the acquisition should consider the seven principles of the logistics:

- *Responsiveness*: Providing the right support at the right time and at the right place. UAV system could be deployed to anywhere easily in a relatively short time and operated efficiently with its logistics support system. The logistics system should provide necessary support in reasonable time. It should also respond to unpredictable failures.
- *Flexibility*: Adapting logistics support to changing conditions. A UAV system may be used for different purposes in any environment around the world. UAV logistics system should adopt itself to the new condition without a decrease in the logistics support and system operation efficiency.
- *Attainability*: The ability to acquire the minimum essential logistics support to begin operations. UAV logistic support package should not be a burden or impediment for the efficient employment of the UAV system. If the UAV logistics footprint is increased because of high level of spares and/or redundant tools/personnel, the mobility of the UAV system decreases while increasing its sustainment cost.
- *Survivability*: Ensuring the functional effectiveness of the logistics infrastructure in spite of degradation and damage. UAV systems will have to monitor their own health by using built-in tests (BIT) and will either have to notify the ground station of any failures or, in the case where data communications are not possible, will have to be preprogrammed with decision criteria on whether or not to continue with the mission [5].
- *Sustainability*: Ensuring adequate logistics support for the duration of the operation. UAV logistics support system should provide the necessary support while enabling required level of UAV system availability and reliability for operations with reasonable acquisition and sustainment costs.

- *Economy*: Effective employment of logistics support assets. UAV support equipment and maintenance procedures should be similar to those of other UAV types and manned aircraft in order to increase interchangeability and commonality while decreasing the acquisition and sustainment costs. It will be beneficial if UAVs use similar consumables and spares to that of manned aircraft.
- *Simplicity*: Avoiding unnecessary complexity in preparing, planning, and conducting logistics operations. Although UAV systems have many different complex systems and new sophisticated technologies, their logistic support should be as simple as possible.

108.3 Logistics Life-Cycle Management

There are many different acquisition process models; most of them are very similar. The United Kingdom Ministry of Defense's acquisition process has six phases: concept, assessment, demonstration, manufacture, in-service, and disposal/termination. The U.S. Department of Defense's acquisition process for a requirement has also six phases. The U.S. Department of Defense's acquisition process [6] with the relevant procedures will be used as a basis in the following parts of the chapter of UAV logistics support with also considering the United Kingdom Ministry of Defense's acquisition process [7].

The U.S. Department of Defense's acquisition process for a requirement starts with the Materiel Development Decision. It consists of an identification of a capability gap, a description of related risks, and a recommendation of whether or not to enter the acquisition process or use a nonmateriel solution. Materiel Development Decision is followed by life-cycle phases.

Figure 108.1 depicts the life cycle phases for an advanced UAV system on a time scale and provides a general understanding how the phases take place. The durations

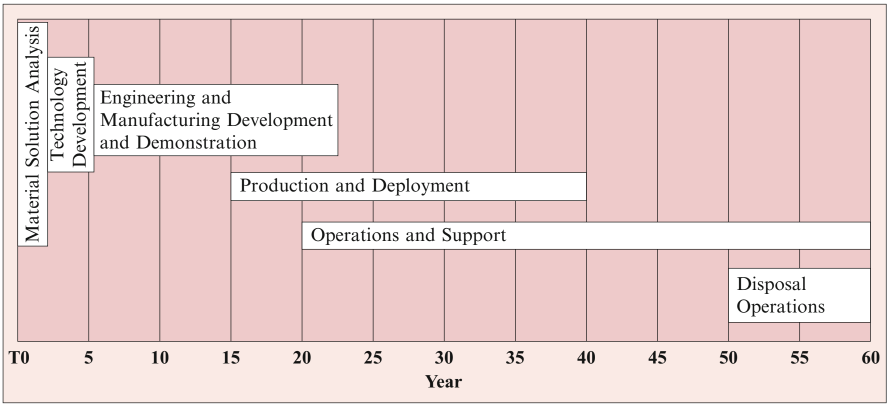

Fig. 108.1 Life-cycle phases

of the total life cycle and the phases depend on the type of the UAV system and the urgency level of the UAV system requirement. For an urgent operational requirement, UAV system development and production may be done in a couple of years, and of course, this simple UAV system could be in the inventory for a relatively short period of time. On the other hand, a complicated UAV system, which is similar to advanced manned aircraft, requires the same life-cycle approach like most manned aircraft.

Life-cycle sustainment planning shall be considered during Materiel Solution Analysis and shall mature throughout Technology Development. A Life-Cycle Sustainment Plan shall be prepared during Technology Development Phase. The planning shall be flexible and performance oriented, reflect an evolutionary approach, and accommodate modifications, upgrades, and reprocurement. At every phases of the life-cycle support, logistics support efforts should be proactive to predict the possible problems before they become serious issues.

Logistics Life-Cycle Management System may be adopted for all types of acquisitions. For example, a user, such as a small Army with a requirement of a couple of UAVs, does not need to follow the first three phases of the life cycle. So, logistics support strategy/package would be prepared during Production and Deployment Phase.

108.3.1 Integrated Logistics Support (ILS)

Integrated logistics support (ILS) is an integrated and iterative process for developing materiel and a support strategy that optimizes functional support, leverages existing resources, and guides the system engineering process to lower life-cycle cost and decrease the logistics footprint (demand for logistics), making the system easier to support [6].

From the earliest stages of the systems development, the acquisition strategy and life-cycle sustainment plan will ensure that the requirements for each of the elements of ILS are properly planned, resourced, and implemented. These actions will enable the system to achieve the operational readiness levels required by the customers at the time of fielding and throughout the life cycle.

ILS is a comprehensive discipline that is applicable to all acquisition activity through life. However, the cost-effective application of ILS requires that there is a balance between benefit and cost. Research shows that over the whole life cycle of a product, the cost of acquisition is small compared to the cost of support, both financially and in unavailability of assets during operations. Reliability and maintainability have large implications on the overall cost of ownership. Thus, investment during development or production in these areas will be saved many times over the whole life of the product [8].

Although there are many descriptions for UAV classes, the NATO UAV classification described in the relevant NATO Strategic Concept [9] is the most widely accepted one. UK Joint doctrine Note 2/11 [10] acknowledges that many platforms may well share characteristics across classes. The type of the UAV system has a critical importance on the logistics support system including ILS:

- *Class I*: These are typically hand-launched, self-contained, portable systems. Payloads are generally fixed electro-optical/infrared (EO/IR), and the system has a negligible logistics footprint.
- *Class II*: These UAVs are typically medium-sized, often catapult-launched, mobile systems. They do not usually require an improved runway surface. The payload may include a sensor ball with EO/IR, a laser range finding or designation capability, synthetic aperture radar and ground moving target Indicator (SAR/GMTI), and signal intelligence (SIGINT) pod. It has a small logistics footprint.
- *Class III*: These are typically the largest and most complex UAVs, operating at high altitude with, typically, the greatest range, endurance, and transit speeds of all UAVs. Payloads may include sensor ball(s) with EO/IR, multi-role radars, lasers, SAR, communications relay, SIGINT, automatic identification system (AIS), and weapons. Most Class III UAVs will require improved areas for launch and recovery and may be piloted from outside the joint operations area via a satellite control link. The logistics footprint may approach that of manned aircraft of similar size.

108.3.1.1 Supportability Analysis

Supportability analysis is the principal tool of ILS. It is the primary means by which the objectives of ILS are achieved and its activities consist of a series of analytical tasks which [7]:

- Influences the design of the product to take account of logistic support considerations
- Identifies support issues, readiness requirements, and cost drivers as early as possible in the product life cycle
- Defines logistic support resource requirements for the life of the product
- Creates the cost-effective physical logistic solution
- Creates the necessary data for logistic support and project decision-making, through life
- Creates the necessary information for logistic support and project decision-making.

108.3.1.2 ILS Elements

The ten ILS elements listed in Fig. 108.2 are described in the following part with using Defense Acquisition University information [6] and U.S. Army Regulation 700–127 Integrated Logistics Support [11].

108.3.1.3 Design Influence

Design influence is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality,

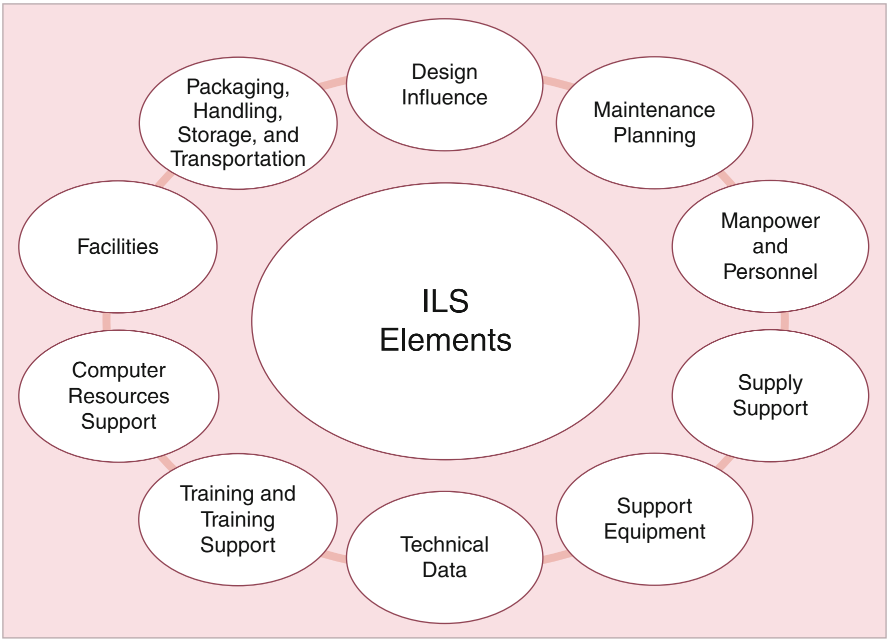

Fig. 108.2 ILS elements

cost, schedule, and user requirements. Logistics design influence acknowledges the inherent characteristic of design in recurrent logistics fundamentals. It seeks to imprint these logistics fundamentals into the end-item design as part of the system configuration and performance parameters.

108.3.1.4 Maintenance Planning

Maintenance planning is the process conducted to evolve and establish maintenance concepts and support requirements for the life of the system. It includes the following:

- Describe the maintenance concept for the system including all levels of maintenance. Identify trade-offs to be performed and maintenance considerations peculiar to the system.
- Identify maintenance tasks required to sustain the end item at a defined level of readiness, including all critical and high tasks.
- Describe the general overall support concepts. Identify proposed or actual skills; tools; test, measurement, and diagnostic equipment (TMDE), support equipment, and so on, to be available at each level of maintenance. Include analysis of possible design for discard of components and repair parts.
- Indicate strengths and weaknesses of each support alternative and the effect of the support concept on the system design, system readiness objectives (SRO),

acquisition and operations & sustainment (O&S) costs, and on affected ILS elements.

- Summarize known or planned interservice support, host nation support (HNS), interim contractor support (ICS) or life-cycle software support (LCCS), and contractor warranties. Identify proposed solutions to potential problems that may result during transition to organic support.
- Include information about planned organic depot maintenance.
- For systems being acquired for multiservice use, address the feasibility and desirability of centralized repair and supply support by a single service, the predominant user in a geographical area, or the one with centralized support capability.

108.3.1.5 Manpower and Personnel

It is the process of identifying and acquiring military and civilian personnel with the skills and grades required to operate and support a materiel system over its lifetime at peacetime and wartime rates.

The overall objective of ensuring that during equipment definition and procurement, full account is taken of the capabilities and limitations of the military and civilian personnel required to operate and maintain the equipment or facility in-service.

108.3.1.6 Supply Support

Supply support includes all the management actions, procedures, and techniques used to determine requirements to acquire, catalog, receive, store, transfer, issue, and dispose of secondary items. This means having the right spares, repair parts, and supplies available in the right quantities, at the right place, at the right time and at the right price.

The objective of supply support is to identify, plan, resource, and implement management actions to acquire repair parts, spares, and all classes of supply to ensure the best equipment/capability is available to support the warfighter or maintainer when it is needed at the lowest possible life-cycle cost.

The process includes provisioning for initial support, as well as acquiring, distributing, and replenishing inventories. This encompasses provisioning for initial support and all end-to-end replenishment supply support and supply pipeline plans and activities. Supply support must be distribution based rather than inventory based and proactive rather than reactive.

During all phases of Life-Cycle Management System, reliability improvement developments should be continuously considered, which may result in a decrease in malfunctions leading to a decrease in spare part quantities.

108.3.1.7 Support Equipment

Support equipment includes all the management actions, procedures, and techniques used to determine requirements for and to acquire the fixed and mobile equipment needed to support the operations and maintenance of a system.

The objective of support equipment is to identify, plan, resource, and implement management actions to acquire and support the equipment (mobile or fixed) required to sustain the operation and maintenance of the system to ensure that the system is available when it is needed at the lowest life-cycle cost. Support equipment consists of all equipment (mobile or fixed) required to support the operation and maintenance of a system. This includes, but is not limited to, ground handling and maintenance equipment, trucks, air conditioners, generators, tools, metrology and calibration equipment, and manual and automatic test equipment. During the acquisition of systems, program managers are expected to decrease the proliferation of support equipment into the inventory by minimizing the development of new support equipment and giving more attention to the use of existing government or commercial equipment.

108.3.1.8 Technical Data

Technical data is all scientific or technical information, equipment publications and technical drawings associated with the system, and its operation, maintenance, and support. Technical data for all support equipment are also included under this ILS element. Although computer programs and related software are not considered technical data, any documentation about computer programs, software support, and output reports is considered technical data.

Technical data are used to provide the necessary information to manufacture and support the system after deployment. The Technical Data Package (TDP) may include engineering drawing and specifications, process descriptions, and documents that define physical dimensions, material composition, performance characteristics, manufacture, assembly, and acceptance test procedures.

Technical manuals information may be presented, according to prior agreement between the contractor and the customer, in any form or characteristic, including hard printed copy, audio and visual displays, electronic imbedded media, disks, other electronic devices, or other media. They normally include operational and maintenance instructions, parts list, and related technical information or procedures exclusive of administrative procedures [12].

The manuals will be drafted in the Engineering and Manufacturing Development and Demonstration Phase and amplified in the Production and Deployment Phase. ICAO Annex 6 [13] requirest that the operations manual shall be amended or revised as is necessary to ensure that the information contained therein is kept up to date. All such amendments or revisions shall be issued to all personnel that are required to use this manual.

108.3.1.9 Training and Training Support

Training and training support consists of the processes, procedures, and techniques used to identify requirements for and to acquire programs of instruction, training facilities, and training systems/devices needed to train/qualify military and civilian personnel to operate and maintain a system proficiently. This includes institutional training, on-the-job training, new equipment training, sustainment training, and individual/crew training.

The goal of training and training support is to plan, resource, and implement a cohesive integrated strategy to train military and civilian personnel to maximize the effectiveness of the doctrine, manpower, and personnel, to fight, operate, and maintain the equipment throughout the life cycle.

As part of the strategy, plan, resource, and implement management actions to identify, develop, and acquire training aids devices simulators and simulations to maximize the effectiveness of the manpower and personnel to fight, operate, and sustain equipment at the lowest total ownership cost.

Training is the learning process by which personnel individually or collectively acquires or enhances predetermined job-relevant knowledge, skills, and abilities by developing their cognitive, physical, sensory, and team dynamic abilities. The "training/instructional system" integrates training concepts and strategies and elements of logistic support to satisfy personnel performance levels required to operate, maintain, and support the systems. It includes the "tools" used to provide learning experiences such as computer-based interactive courseware, simulators, and actual equipment (including embedded training capabilities on actual equipment), job performance aids, and interactive electronic technical manuals.

All UAV systems should be developed with the maximum use of personalized learning management, simulation-enabled computer-based training and virtual instruction. Training for support equipment should also be a part of the training package.

108.3.1.10 Computer Resources Support

Computer resources support is all the management actions, procedures, and techniques used in determining requirements and acquiring hardware, software, facilities, documentation, personnel, and manpower required to develop and sustain computer resources for operation and maintenance of a system, including planning and support requirements for post-deployment software.

Computer resources support element evaluates the operational and support capabilities of the various computer resource systems. The evaluations will center on the overall operational and support concepts of computer resources, the effectiveness of computer resources, quality and accuracy of data, and man/machine interface. The computer resources support evaluation will include evaluation of the built-in test (BIT) system, all computer resources that interface with the test article, all off-equipment computer resources the maintainer may interface with to complete a task, and all test article systems involving computer resources [14].

As the primary end item, support equipment, and training devices increase in complexity, more and more software is being used. The expense associated with the design and maintenance of software programs is so high that one cannot afford not to manage this process effectively. It is standard practice to establish some form of computer resource working group to accomplish the necessary planning and management of computer resources support. Computer programs and software are often part of the technical data that defines the current and future configuration baseline of the system necessary to develop safe and effective procedures for operation and maintenance of the system. Software technical data comes in many forms to include, but not limited to, specifications, flow/logic diagrams, computer software configuration item definitions, test descriptions, operating environments, user/maintainer manuals, and computer code.

108.3.1.11 Facilities

Facilities consist of all the management actions, procedures, and techniques used to determine requirements for and to acquire the permanent and semi-permanent real property assets needed to support operation, maintenance, and storage of a system and its support equipment.

The objective of facilities is to identify, plan, resource, and acquire facilities that will allow storage, maintenance, and training to maximize the effectiveness of a systems operation and logistic support system at the lowest life-cycle cost and enable responsive support to the warfighter by identifying and preparing plans for the acquisition of facilities.

Facilities consist of both semipermanent and permanent real property assets for the support of a system. Studies that define location, types of facilities, facility improvements, space needs, security requirements, environmental requirements, and equipment are also considered in facilities. This element includes new and modified facilities for supply storage, equipment storage, ammunition storage, maintenance, etc.

Although nearly all of the UAV systems are mobile systems, most of them require some infrastructure such as hangars, aprons, taxiways, runways, buildings, communication lines, and electricity. The facilities for support equipment should also be a part of the facility requirement. Moreover, facilities for the storage of hazardous material such as lithium batteries required for UAV operations must be planned.

108.3.1.12 Packaging, Handling, Storage, and Transportation (PHST)

The PHST concept describes any anticipated special considerations for the packaging, handling, storage, and transportability required for deployment and sustainment of the system as well as the process for determining these requirements. The operational environment conditions (temperature, humidity, etc.) and potential for use of hazardous materials must be considered.

Transportation of a UAV system will range widely from the one or two man-carried backpacks of a small UAV to a strategic UAV system with a requirement of strategic airlift. Since the strategic airlift platforms are very rare at the moment, the air transportation of the UAV system requires special consideration. Transportation of the UAV system from main base to the operational deployment location should be planned carefully.

A typical medium altitude long-endurance (MALE) UAV system like ANKA, Heron, MQ-1B Predator, or MQ-9 Reaper consists of 4 UAV platforms, one or two ground control station, one or two ground data terminal, some support equipment, and an important amount of spares. These systems and equipment should be packed properly for the air transportation. Strategic airlift is required for the deployment of such UAV system. Although the required airlift capacity depends on the type of the

UAV system, typically two to three An-124, IL-76, or C-17 sorties, and six to seven C-130 or C-160 sorties are sufficient.

108.3.2 Performance-Based Logistics (PBL)

B.D. Coryell [15] states that PBL means different things to different people, but principally it is defined as establishing a contract or agreement with a logistics provider for a specified level of performance for an item at a system, subsystem, or component level. This level of performance can be achieved by a contractor, the government, or a combination of both.

According to Defense Acquisition University document of Performance-Based Logistics: A Program Manager's Product Support Guide [16], PBL is the purchase of support as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapons system through long-term support arrangements with clear lines of authority and responsibility. Simply put, performance-based strategies buy outcomes, not products or services.

The application of PBL can provide numerous benefits. The most visible benefits of PBL are in the operational portion of the program life. PBL should reduce logistics costs and footprint, increase system reliability, and mitigate obsolescence [15]:

- *Reducing logistics cost and footprint*: PBL will get the best capability return on the funds available in the Defence Forces to support weapons systems. In other words, incentive-oriented agreements should reduce product support costs through reduced infrastructure, reduced obsolescence, and reduced provisioning and data requirements. PBL will provide more visibility and control over operations and support costs which will ultimately improve the ability to manage program resources. With this visibility and control, PBL should create a reduction in the overall demand for logistic support and reduce the logistics footprint.
- *Increasing system reliability*: Incentive oriented agreements will improve weapon system availability and provide warfighters with increased operational readiness. The provider is provided incentives to ensure that set levels of system support performance are achieved. If the contract is correctly incentivized, the items, components, or subsystems that configure the weapon system will be designed to fail less. The PBL supplier then has the financial incentive to continuously improve performance because it has a bottom-line impact. This in turn will improve customer satisfaction. PBL will result in confidence in the warfighter that the system will provide the required performance capabilities when needed in combat.
- *Mitigating obsolescence*: PBL provides a powerful tool for mitigating obsolescence and making continuous modernization a reality for legacy weapon systems. PBL clearly fulfills the need for continuous modernization and obsolescence mitigation. Because it provides incentives for private industry to continually improve reliability and the performance of the managed system. In this manner, private industry conducts research and development and acquisition activities

in-stride with performing their contracted logistics support contract. Consistent with evolutionary acquisition practices and the spiraling of technology as it matures, the PBL contractor can leverage research and development efforts for spirals into legacy component system reliability.

The essence of PBL is buying performance, instead of the traditional approach of buying individual parts or repair actions. It is important to note that, although the fundamental concept of buying performance outcomes is common to each PBL arrangement, the PBL strategy for any specific program or commodity must be tailored to the operational and support requirements of the end item.

A key component of any PBL implementation is the establishment of metrics. Since the purpose of PBL is "buying performance," what constitutes performance must be defined in a manner in which the achievement of performance can be tracked, measured, and assessed [16]. U.S. DoD Momerandum [17] lists the following criteria to be used for PBL performance objectives:

- *Operational availability*: The percent of time that a system is available for a mission or the ability to sustain operations tempo.
- *Operational reliability*: The measure of a system in meeting mission success objectives (percent of objectives met, by system). Depending on the system, a mission objective could be a sortie, tour, launch, destination reached, or other service- and system-specific metric.
- *Cost per unit usage*: The total operating cost divided by the appropriate unit of measurement for a given system. Depending on the system, the measurement unit could be flight hour, steaming hour, launch, mile driven, or other service- and system-specific metric.
- *Logistics footprint*: The government/contractor size or "presence" of deployed logistics support required to deploy, sustain, and move a system. Measurable elements include inventory/equipment, personnel, facilities, transportation assets, and real estate.
- *Logistics response time*: The period of time from logistics demand signal sent to satisfaction of that logistics demand. "Logistics demand" refers to systems, components, or resources (including labor) required for system logistics support.

There is no "one-size-fits-all" approach to PBL. Similarly, there is no template regarding sources of support in PBL strategies. It comprises a combination of public (organic) and private (commercial) support sources. Finding the right mix of support sources is based on best value determinations of inherent capabilities and compliance with statutes and policy. This process will determine the optimum PBL support strategy within the product support spectrum, which can range from primarily organic support to a total system support package provided by a commercial original equipment manufacturer [16].

According to University of Tennessee and Supply Chain Visions' White Paper [18], PBL may be implemented at four levels:

- *Level 1 – Component*: The lowest level of PBL implementation is at the system component level, such as aircraft tires. At this level the "performance" purchased is the consistent and timely delivery of needed components. The scope of support

responsibility for the contractor is generally narrow – focusing primarily on supply chain activities.
- *Level 2 – Major subsystem*: At level 2 the scope of support and corresponding performance outcomes broadens, and the customer/operator-contractor relationship begins to become more collaborative. The focus is not just on delivery speed, but on broader improved material availability, which necessitates enlarging the scope of support to include not only supply chain activities but also encompassing repair processes, engineering and technical support, configuration management, and even minor modifications and process improvements. One of the best examples of a major subsystem PBL is the GE F404 Aircraft Engine.
- *Level 3 – Platform availability*: At this level the scope of support is the buying warfighter performance. The warfighter doesn't think in terms of employing components or subsystems; their focus is on the availability and readiness of weapon system platforms – an aircraft, a ship, or a tank – the tools of combat capability. Consequently, this level of PBL transfers even more responsibility for management of support activities to the contractor. One example of a level 3 PBL is the Lockheed Martin and U.S. Air Force Total System Support Partnership (TSSP) program involving the F-117 Nighthawk.
- *Level 4 – Mission*: While level 3 PBLs optimize weapon system availability for the warfighter, what the warfighter ultimately needs in combat is not only for the system to be available to perform its mission but to successfully complete the mission. One of the best examples is the Army Shadow Tactical Unmanned Aerial Vehicle program.

108.4 Logistics During Materiel Solution Analysis Phase

The purpose of Materiel Solution Analysis Phase is to assess potential materiel solutions. During Materiel Solution Analysis Phase, ILS issues, supportability deficiencies, and opportunities for improvements and efficiencies are evaluated.

Prior to the Materiel Development Decision, supportability objectives must be clearly defined. System supportability objectives provide the basis upon which product support capabilities are evaluated. They include design, technical support data, and maintenance procedures to facilitate detection, isolation, and timely repair and/or replacement of system anomalies.

The goal is to ensure product support capabilities, requirements, and risks are considered early and throughout the acquisition continuum, in order to minimize support costs, provide end users with required resources, and attain materiel availability objectives.

To facilitate an evaluation of product support capabilities, from concept through fielding, required system reliability, planned maintainability, and supportability methods, practices, and processes must be clearly defined and integrated with the systems engineering process. Additionally, the concept of operations must be defined to provide the basis for assessing system requirements and overall product support capabilities, as well as the initial definition of the system maintenance and support concept for sustainment.

Life-cycle sustainment planning and execution should seamlessly span a system's entire life cycle, from Materiel Solution Analysis to disposal. It translates force provider capability and performance requirements into tailored product support to achieve specified and evolving life-cycle product support availability, reliability, and affordability parameters.

108.5 Logistics During Technology Development Phase

The purpose of Technology Development Phase is it to reduce technology risk and to determine the appropriate set of technologies to be integrated into the full system. It is an iterative process designed to assess the viability of technologies while simultaneously refining user requirements. The Technology Development Phase begins when a materiel solution has been endorsed in the end of the Materiel Solution Analysis Phase.

Logistics support goals for the Technology Development Phase are to refine sustainment objectives and requirements, demonstrate system feasibility and mature technology, and design in sustainment and establish Product Support Package requirements.

The objective of the Technology Development Phase is to reduce technology risk. From a sustainment standpoint, this means designing critical supportability aspects into the system and developing the system support package.

A sustainment concept should be prepared in the Materiel Solution Analysis Phase. At the beginning of the Technology Development Phase, the data gathered while developing the sustainment concept should be used to establish sustainment requirements. The sustainment concept should also feed the design of the product support package. The Product Support Package has two major components:

- The Maintenance Plan and Requirements describe the management approach for developing and implementing the maintenance plan.
- Product Support Package Elements include an overview of technical documentation (paper and electronic), Test/Support & Calibration Equipment, Manpower & Training/Computer-Based Training, supply support, packaging, handling, storage and transportation, facilities, and computer resources support.

The program manager should develop a product support strategy for life-cycle sustainment and continuous improvement of product affordability, reliability, and supportability while sustaining readiness. The support strategy is a major part of the acquisition strategy which includes design, technical support data, and maintenance procedures to facilitate detection, isolation, and timely repair and/or replacement of system anomalies. This includes factors such as diagnostics, prognostics, real-time maintenance data collection, and human system integration considerations.

108.6 Logistics During Engineering and Manufacturing Development and Demonstration Phase

The purpose of Engineering and Manufacturing Development and Demonstration Phase is to develop a system or an increment of capability, complete full system integration, develop an affordable and executable manufacturing process, ensure operational supportability with particular attention to minimizing the logistics footprint, implement human systems integration, design for producibility, ensure affordability, and demonstrate system integration, interoperability, safety, and utility.

During Engineering and Manufacturing Development and Demonstration Phase, Product Support Plan is developed. Product (or logistics) Support Plan is a document that outlines how product support and sustainment of a weapon system will be managed over its life cycle. Product support is the package of support functions necessary to maintain the readiness and operational capability of weapon systems, subsystems, and support systems. It encompasses all critical functions related to weapon system readiness, including materiel management, distribution, technical data management, maintenance, training, cataloging, configuration management, engineering support, repair parts management, failure reporting and analyses, and reliability growth.

Logistics support model is to be defined at System Development and Demonstration Phase. The source of the support may be organic or commercial, but the product support plan's primary focus is to optimize customer support and achieve maximum availability at the lowest total ownership cost.

UAV platform may incorporate a modular design for flexible payload configuration. The configurable pods and payload bays can house a wide array of sensors and weapons. Fault isolation within UAV system must mostly be accomplished by using built-in test (BIT).

The design of the UAV systems should consider the climatic extremes ranging from high temperatures in arid regions, through frigid temperatures with associated ice and snow, to tropical climates with high relative humidity and excessive rainfall.

108.7 Logistics During Production and Deployment Phase

The purpose of Production and Deployment Phase is to achieve an operational capability that satisfies the mission need. Operational test and evaluation shall determine the effectiveness and suitability of the system. During the Production and Deployment phase, the system should achieve operational capability that satisfies mission needs. It has two main stages: Low-Rate Initial Production and Full-Rate Production and Deployment.

Low-Rate Initial Production (LRIP) is intended to result in completion of manufacturing development in order to ensure adequate and efficient manufacturing capability to produce the minimum quantity necessary to provide production-representative articles for testing and evaluation.

Full-Rate Production and Deployment should be based on the results of testing initial production articles and refining manufacturing processes and support activities which indicate the product is operationally capable, lethal and survivable, reliable, supportable, and producible within cost, schedule, and quality targets.

During Production and Deployment Phase, all documentation is finalized, necessary training of personnel for maintenance and operations are accomplished, and Product Support Package/Performance-Based Logistics (PBL) is implemented.

108.8 Logistics at Sustainment (Operations and Support)

Logistics plays a crucial role at sustainment phase, which takes place between acquisition to disposal phase. In logistics point of view, sustainment is the longest part of the ILS. This period lasts 10–30 years up to requirements, economy, and technological trends. During this period UAV systems are required a perfectly coordinated and regularly manipulated logistic system.

The purpose of logistics at sustainment is to execute a support program that meets materiel readiness and operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle.

During sustainment, logisticians execute a support program that meets materiel readiness (availability) and operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle. When the system has reached the end of its useful life, it shall be disposed in an appropriate manner.

System modifications are initiated whenever necessary to improve performance and reduce ownership costs. The users conduct continuing reviews of sustainment strategies, utilizing comparisons of performance expectation as defined in performance agreements against actual performance measures. Sustainment strategies are revised, corrected, and improved as necessary to meet performance requirements.

108.8.1 Supply

Supply is an essential part of logistics for all kind of systems. In maintenance point of view, its necessity comes from the requirement of material flowing, because maintenance process can't occur without it. In aviation supply plays a crucial role, and also UAV systems pursue this rule. This section of logistics deals with acquisition, packaging, shipping spares, and meeting them with technicians.

To supply all the equipment for an Unmanned Air System (UAS) rapidly is required to establish a reliable and robust supply mechanism. Operational requirements, especially expected flying hours, declare the time toleration for spare packages. In order to manage products and ensure high levels of equipment availability with an online asset management tool which tracks complete UAS flying hours, life expired and obsolete parts are replaced in a timely manner that fits in the mission cycle. Emergency logistical support is also maintained through the level of spares management and rapid distribution system. The supply materials may be consumables or replaceable components. Reg Austin defines them as follows [19];

– Consumables: Depending upon the size of the system and the quantities required, lubricants, cleaning materials, batteries, and fuel may be carried within the Control Station (CS) especially if the CS vehicle uses the same type of fuel as the aircraft. Otherwise, for larger systems or for safety reasons, fuel will be carried in a separate vehicle or browser.
– Replaceable components: These kinds of components are listed in the Maintenance Manuals, and the replenishment of these to the UAV system's operating base is required from the logistics support organizations.

To supply all of the required equipment rapidly, a robust and well-defined chain must be established. This chain is generally called as supply chain. A supply chain is a complex logistics system in which raw materials are converted into finished products and then distributed to the final users. It includes suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets. At this point reflection of the supply chain on the supply process of UAVs is inspected. Not only the regular periodic maintenances but also the unplanned repairs require spare materials. Establishing a supply-flow method is a crucial target for logistic planner. For this purpose an effective and optimal supply chain must be planned before sustainment and applied during sustainment. In planning phase the following factors are taken into account, and also this list may increase or decrease according to the requirements:

- Flying hours: The expected flying hours of UAV in a year, also this includes consecutive flying hours
- Number of the UAVs and ground assets: The number of UAVs and ground assets achieved during procurement and probable loss and additive assurance amount during sustainment
- Percentage of availability during life cycle: The amount of available UAVs and ground assets in a definite period of time during life cycle
- Probable service life: Expected life cycle of UAVs and whole related assets (ground assets, avionics, payloads, etc.)
- Obsolescence program: To put probable expired and obsolete parts on a time table

By using the aforementioned requirements, an analysis is conducted, and an application plan is prepared. This plan must support all the maintenance levels. Additionally this plan should meet the readiness requirements of UAV system. After preparing the plan, it is applied to practical life. A supply chain is established, and related stakeholders are connected to the chain network. An example of UAV system supply chain is shown in Fig. 108.3.

108.8.2 Maintenance

Maintenance is most critical and time-consuming part of logistic activities during the life cycle of all kind of systems. Within the airline industry, it has been estimated

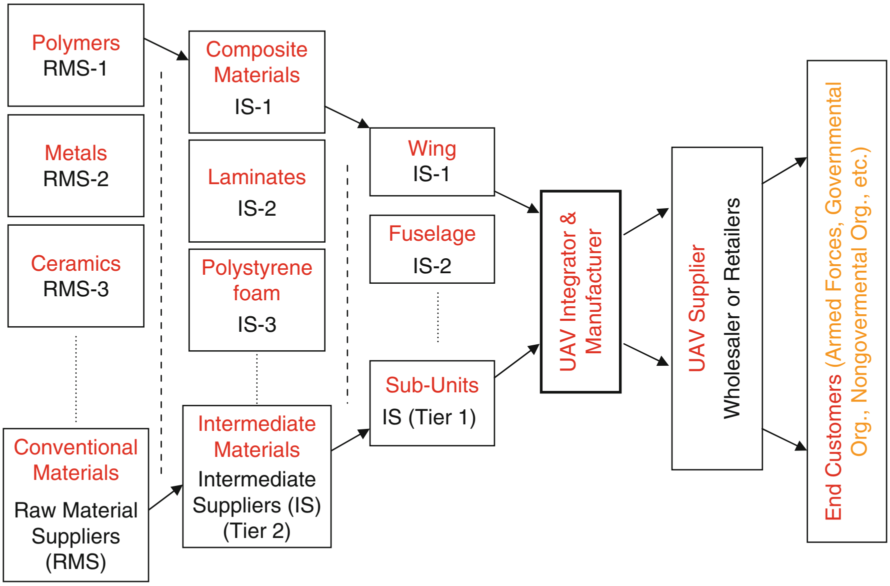

Fig. 108.3 A supply chain example for UAV system

that for every hour of flight, 12 man-hours of maintenance occur. Maintenance was defined as any activity performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle. Maintenance generally includes the following:

- Assembly
- Fuelling
- Preflight inspections
- Repairs
- Regular maintenances
- Software updates

Maintenance activities may involve the vehicle as well as equipment such as the UAV ground control station. According to the maintenance point of view, activities can be classified as either corrective or preventative. Corrective maintenance involves the repair or replacement of systems that have experienced wear or damage. In many cases, corrective maintenance is nonroutine and is performed in response to an operational event such as a hard landing or a system failure. Nonroutine tasks are more likely to require fault diagnosis, problem-solving, and special skills. Preventative maintenance tasks are performed before a problem occurs and may involve tasks such as inspections, lubrication, or the replacement of components at predetermined intervals. Preventative maintenance tasks are typically routine and tend to require a more limited range of skills and knowledge than corrective maintenance tasks [20].

108.8.2.1 Maintenance Plan for UAVs

In general perception a maintenance plan describes the requirements and tasks to be accomplished for achieving, restoring, or maintaining the operational capability of the UAVs. A maintenance plan is a concise summary of maintenance requirements that is performed on the system. It is prepared at the beginning of the project with the other project plans. A maintenance plan should preserve the inherent design levels of the UAV subsystems reliability with minimum expenditure of maintenance and support resources.

A maintenance plan establishes and defines the line-replaceable units (LRUs) categories in groups of repairable LRUs and consumable LRUs that required maintaining UAVs. For each LRU, the maintenance plan identifies the maintenance level authorized to perform the required maintenance tasks. The maintenance plan also provides Source, Maintenance, and Recoverability (SMR) codes, which summaries the maintenance concept of each LRU.

For preparing a maintenance plan, some preliminary estimated information is used. This information reflects the general requirements of UAVs. These requirements include, but are not limited to, the following:

– Flying hours: The expected flying hours of UAV in a year, also this includes consecutive flying hours.
– Reliability: The probability of realization of the required function in identified case and in between a certain time.
– MTBF (mean time between failures): Average time duration of a system or equipment not working or malfunctioning in a certain interval.
– MTBM (mean time between maintenance): Average time between all maintenance actions (protective and corrective).
– MCMT (mean corrective maintenance time): Mean corrective maintenance time is composed of some elements. It is mathematically modeled as follows:

  $MCMT = Tp + Tfi + Td + Ti + Tr + Ta + Tco + Tst$
  Tp = Mean readiness time
  Tfi = Trouble shooting time
  Td = Mean disassembling time
  Ti = Mean replacing time
  Tr = Mean assembling time
  Ta = Mean corrective time
  Tco = Mean checkout time
  Tst = Mean starting time

– Mean preventive maintenance time – MPT: The preventive maintenance contains the procedures to keep the system in a certain performance level and the functions such as periodic inspections, services, and calibration. MPT is the average of time duration passed during preventive maintenance.
– Logistic delay time – LDT: Total duration of required time to receive the repair equipment, spare parts, or maintenance test equipment.
– Maintenance labor hours per month – MLH/month: The total cost of monthly maintenance labor man-hour.
– Probable expired and obsolete parts on a time table.

After determining the life-cycle requirements of UAVs, a maintenance plan is established by using the information of requirements and the experiences of contractor and customer. Maintenance plan shapes the maintenance structure during sustainment.

108.8.2.2 Maintenance Levels

Maintenance level structure is a strategic decision which depends on the budget of project, verdict of the contractor, and the facilities of customer. Also defining boundaries and abilities of these levels is another decision area. Decision process for maintenance levels starts in the planning phase. Maintenance levels and borders of them, the responsibilities of the project stakeholders, are determined according to the requirements and defined in the maintenance plan.

The organizational structure of maintenance will be designed to produce appropriate sortie rates in order to meet requirements. Both customer and contractor personnel will operate the system and provide technical expertise and maintenance capability down to the subcomponent level. Because of the requirement to maintain UAVs at the same level of safety and availability as manned aircraft, a similar maintenance concept and execution like manned aircraft is required, especially for the UAVs larger than small UAVs.

In order to establish a reliable and robust maintenance system for UAVs, probable generic operational employment scenarios can be used during the planning phase. These scenarios are composed of, but not limited to, the following:

- First, create a required UAV employment scenario
- Define periodic maintenance requirements such as operational-level maintenance, depot-level maintenance
- Define possible disorders such as mishaps and emergencies which create logistic requirements
- Show all operational steps and logistic footprints on a sketch

As mentioned above and in the maintenance plan subsection, planning is the dominant part of shaping the maintenance level. At this point it is proper to explain the maintenance levels. In general maintenance concept has three maintenance levels. These levels are operational-level (O-Level), intermediate-level (I-Level), and depot-level (D-Level) maintenances. The relation of levels is shown in Fig. 108.4.

In the below figure the relationship and the capabilities of the maintenance levels are outlined. Three-level maintenance activities can be summarized as follows [21];

- Operational-level maintenance: This level consists of the on-equipment tasks necessary for day-to-day operation, including inspection and servicing and remove-and-replace operations for failed components
- Intermediate-level maintenance: This level consists of off-equipment repair capabilities possessed by operating units and in-theater sustainment organizations. These capabilities can be quite extensive and include remove-and-replace operations for subcomponents of line-replaceable units (LRU), local manufacture, and other repair capabilities

- Depot-level maintenance: This level consists of all repairs beyond the capabilities of the operating units, including rebuild, overhaul, and extensive modification of equipment platforms, systems, and subsystems

Generally the responsibility borders between maintenance levels are drawn by using maintenance allocation chart (MAC). MAC reflects the responsibility allocation for the performance support tasks for each LRU and assigns the tasks to the proper maintenance activity in accordance with the maintenance concept. MAC structure generally includes Logistic Control Number (LCN), Description (item nomenclature), and Source Maintenance Recovery (SMR) codes.

The details and aims of the maintenance levels and their capabilities are detailed in the following subsections.

Operational-Level (O-Level) Maintenance

This is the first step of the maintenance levels, so it has the least maintenance capability. The maintenance activities at the O-Level are performed on the UAV systems and subsystems in the flight line and in the hangar. O-Level maintenance for UAV system consists of those maintenance tasks intended to keep the system operational and prevent deterioration.

O-Level maintenance is performed by operating units on a day-to-day basis in support of their operations. The O-Level maintenance mission is to maintain assigned UAV equipment in a full mission-capable status while continuing to improve the local maintenance process. While O-Level maintenance may be done by I-Level or D-Level activities, O-Level maintenance is usually accomplished by maintenance personnel assigned to operation area. Generally, O-Level maintenance can be grouped under "inspections, servicing, and handling" categories.

The main problem in O-Level is fuselage defects of UAVs. Most small UAVs and some parts of big UAVs are produced by composite materials. During their employment, the air vehicles can be smashed, cracked, chipped, or dented. Generally O-Level technicians are not trained to repair composites.

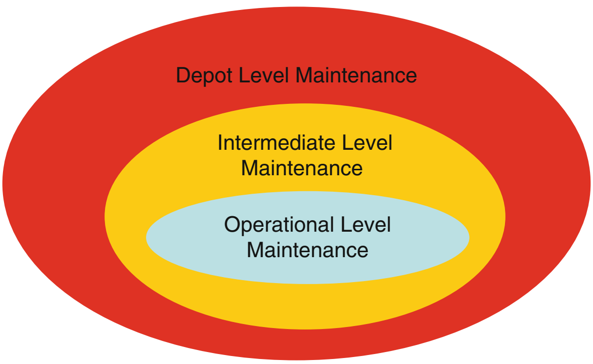

Fig. 108.4 Relationship of maintenance levels

O-Level maintenance includes, but is not limited to, the following activities:

- UAV system servicing
- Failure detection and isolation using the UAV System built-in test (BIT)
- Replacement of faulty LRUs
- Limited cabling and structural repair on UAV System and subsystems
- Preventive maintenance checks and services (UAV System serviceability checks, cleaning, etc.)
- Periodic inspection or replacement to comply with scheduled maintenance requirements, corrosion prevention, detection, and removal
- Inspection after abnormal events
- Functional tests
- Loading software to UAV System LRU
- Simple adjustments/calibrations
- Packing for transportation
- Discarding defective LRUs
- Shipping defective LRUs to intermediate level

Intermediate-Level (I-Level) Maintenance

I-Level maintenance has more capabilities than O-Level maintenance. I-Level personnel focus on only repair and testing elements and sub-elements of UAVs, rather than operational activities. This level is an intermediate level but not in the middle; its abilities are closed to D-Level abilities. I-Level personnel are not only composed of technicians but also engineers and administrative. Generally I-Level maintenance organization is made up of maintenance managers, staff divisions, and production divisions.

I-Level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the lowest practical resource expenditure.

The maintenance activities that are performed at I-Level involve maintenance procedures, which require specialized skills and resources for inspection, testing, refurbishment, or repair. I-Level maintenance includes, but is not limited to, the following activities:

- Detection and isolation, by using test equipment for selected items, the faulty SRU (shop replaceable unit) in the faulty LRU (line-replaceable unit) which was sent from the O-Level
- Test of LRU, by using test equipment, whose SRU has been replaced
- Calibration of designated equipment
- Processing aircraft components from stricken aircraft
- Providing technical assistance to supported units
- Performance of on-aircraft maintenance when required
- Age exploration of aircraft and equipment under reliability-centered maintenance (RCM)
- Loading software to LRU
- Intermediate-Level LRU periodic maintenance
- Off-system limited cabling and structural repair

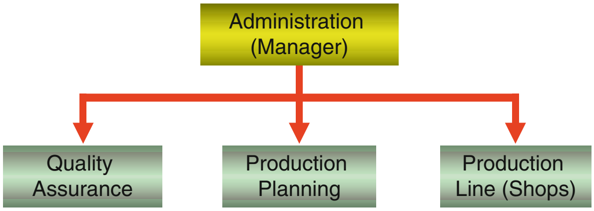

Fig. 108.5 Organizational chart for I-Level maintenance

I-Level maintenance has more capabilities than O-Level maintenance. This capability increase is caused by both personnel and equipment. In I-Level maintenance the technicians are well trained about the systems; there are few engineers taken system course. Also this maintenance level covers advanced test equipments, Automatic Test Equipments (ATEs), I-Level technical orders (TOs), and shops. The shops are electrical, electronics, mechanical, and composite shops. In addition to these capabilities, a forward distribution depot consists in I-Level maintenance structure. I-Level has considerable capability, but this capability is limited when compared with the D-Level maintenance capabilities. Notwithstanding I-Level has a chance for obtaining new abilities, but not as much as D-Level.

In order to establish I-Level maintenance, a segmentation structure is required. This structure is not required in O-Level maintenance, because it is fulfilled with only a group. Every sub-function of O-Level can be realized with one or few people. But the sub-functions of I-Level require more personnel. Basic organization structure for I-Level maintenance is shown in Fig. 108.5.

Depot-Level (D-Level) Maintenance

Maintenance actions that cannot be accomplished at O or I-Level are conducted in D-Level maintenance. D-level maintenance has the capability to do anything necessary to repair failed equipment or to make periodic D-Level maintenances. D-level maintenance facilities have the wider range of tools, test equipment, and knowledgeable maintenance personnel. Fabrication of structural parts, major overhauls, refurbishment, and rebuilding of equipment can be done at D-Level.

D-level maintenance is performed at aviation industrial establishments to ensure continued flying integrity of airframes and flight systems during subsequent operational service periods. D-level maintenance is also performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items. D-level maintenance supports O-level and I-level maintenance by providing engineering assistance and performing maintenance beyond their capabilities.

The maintenance activities that are performed at D-Level maintenance of UAVs involve maintenance procedures, which require specialized skills and resources for inspection, testing, refurbishment, or repair. D-Level maintenance of UAVs generally includes the following activities:

- Standard D-level maintenance of UAVs and ground assets
- Rework and repair of engines, fuselage, and components
- Faulty SRU repair

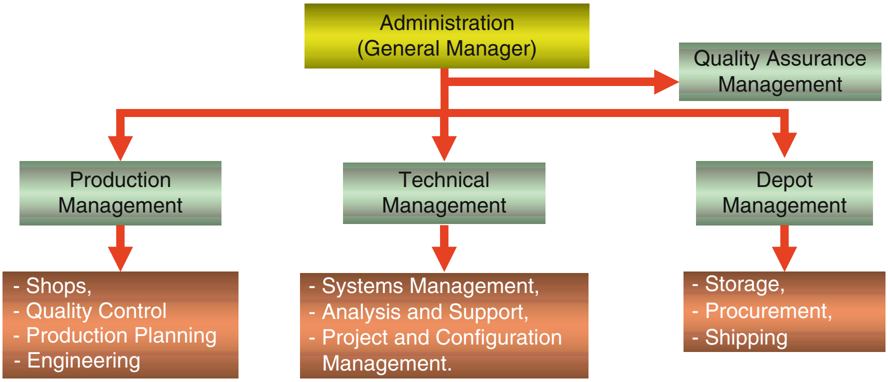

Fig. 108.6 Organizational chart for D-Level maintenance

- Extensive structural control, repair, and modifications
- Calibration exceeding O- and I-Levels
- Harness repair exceeding O- and I-Levels
- Configuration control, authorization, and classification
- Update maintenance plans and documents when required
- Technical management
- Depot-level periodic maintenance and inspection
- Participate in design change process to improve maintenance

Organization structure of D-Level maintenance is relatively larger than that of I-Level. As mentioned above D-Level includes manufacturing parts, modifying, testing, inspecting, sampling, and reclamation. In order to achieve these functions, D-Level has a comprehensive organizational structure. Every sub-function of D-Level requires an additional segmentation structure. A general organization structure for D-Level maintenance of UAVs is shown in Fig. 108.6.

Also it is beneficial to deal with the kinds of shops in D-Level maintenance of UAV systems. The shops cover whole facilities of UAV system. This means that they cover not only UAVs but also ground assets. For this purpose the shops and their capabilities are listed as follows:

- Structural (composite) shop: Standard structural repair processes and required kits, composite material processes (repair, replace, modify, etc.), wet layups technology, hinge replacement, panel replacement, integral fuel tank sealing, finish and touch-up repairs, and structural checks
- Mechanical shop: Standard mechanical repair processes and required kits, maintenance and repair processes of UAV motors and propellers, maintain processes of motor-and motor and related parts, replacement of faulty mechanical LRU
- Electronic shop: Standard electronic repair processes and required kits, fault detection and isolation, removal and replacement capability for faulty LRUs,

repair and maintenance processes for avionics, motor electronics (Full Authority Digital Engine (or Electronics) Control – FADEC), payloads and ground assets, and fault detection and isolation for data link
- Electrical shop: Standard electrical repair processes and required kits, processes for defining condition of electrical assemblies, fault detection and isolation for UAVs electricity, and system generator and power supplies

108.8.3 Configuration Management

In this part configuration management (CM) process for UAV systems is identified and described. CM is a field of management that focuses on establishing and maintaining consistency of a system or product's performance and its functional and physical attributes with its requirements, design, and operational information throughout its life [22]. Before entering into more details about CM, it will be beneficial to give some related definitions. The definitions are given in terms of UAV.

– Configuration: Physical and functional characteristics of a UAV system that is defined in the technical documents and reached form after using.
– Configuration verification: Conformance control of a UAV system according to configuration documents.
– Configuration item (CI): CI refers to the fundamental structural unit of a configuration management system.
– Configuration identification: Selection of configuration item (CI), defining required configuration document for every CI, giving ID numbers for technical documents and CIs.
– Configuration baseline: A baseline is a group of configuration items (products, deliverables) developed during a specific phase of the development process that has been formally accepted. Once the baseline is established, changes to the items can only be done through a formal change process. There are five baselines typically used in system development: functional, allocated, design, product, and operational. The functional baseline may contain an initial investigation baseline, a feasibility study baseline, and a requirements definition baseline.
– Configuration control (CC): Endorsing proposed engineering changes to UAV systems systematically and executing them fully coordinated and documented.
– Configuration control board (CCB): The technical and administrative board that makes decisions regarding whether or not engineering change proposals (ECPs) to an endorsed configuration document should be implemented.
– Configuration management plan: A managerial discipline applied to a UAV system for controlling and tracing functional and physical specifications during whole life cycle.

After giving the above definitions, it will be beneficial to depict the basic elements of configuration management. Elements of configuration management are shown in Fig. 108.7.

UAV systems have both air and ground assets. Also they have many electronic hardware parts, complicated and different kinds of software. As many other

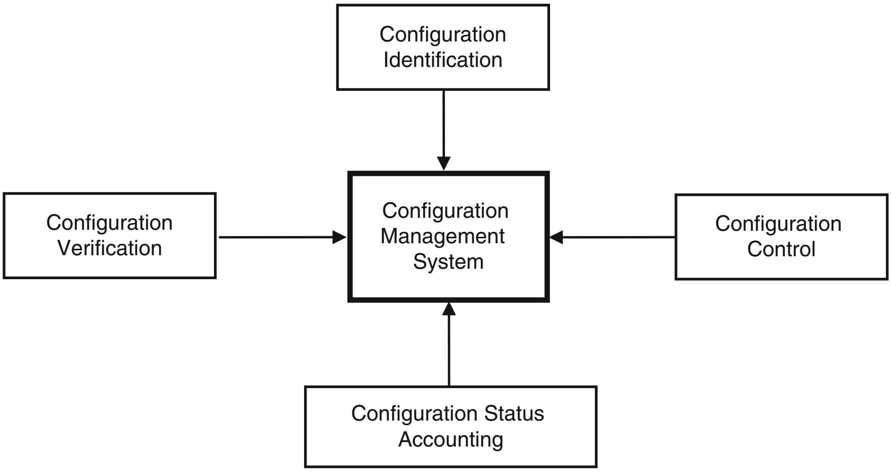

Fig. 108.7 Elements of configuration management system

complicated systems, configuration management is an essential assignment for an organization. Otherwise managing and maintaining a system during its life cycle is almost impossible. In fact configuration management system for UAVs is not different than any other complicated system. For this purpose the elements of configuration management system are given in general. In the following part the elements of configuration management system are given separately. By the way the elements will be elaborated in the following headings:

108.8.3.1 Configuration Identification

Configuration identification is the process of identifying the attributes that define every aspect of a configuration item. In order to fulfill configuration identification process, the following operation should be performed successively:

- Selection of configuration item must be realized
- A system must be established for disseminating configuration documents
- Selection of the documents used for developing configuration baseline must be done
- The interfaces must be identified and documented
- Functional, allocated, and product baselines must be composed
- Configuration item, configuration definition, series, and band numbers must be identified
- A correlation among branding, labeling, configuration documents, and the other data must be established

108.8.3.2 Configuration Control

Configuration control ensures that proposed engineering changes to configuration items are fully coordinated and documented. Configuration control is tailored during each life-cycle phase of a configuration item as follows:

- Acquisition Phase: During this phase configuration control will be applied to a new item's operational and functional requirement; during this phase configuration control will be applied to all documents which establish the functional baseline documentation. This phase represents the acquisition of a new device and as such establishes the product baseline documentation.
- Operational Support Phase: During this phase configuration control will be applied to any revisions to the established functional and product baseline documentation of an existing item. This phase represents the modification/update of existing devices.

An engineering change proposal is the standard method for proposing changes to a configuration item. Engineering change proposal is used to initiate engineering change proposals. There are two categories of engineering change proposals:

- Solicited. Solicited ECPs are submitted by the contractor in response to a written request made by the government. At NAWCTSD, it occurs as a result of a solicited ECP on a weapon system platform (WS/ECP) from the major claimant which, in turn, could affect the training device/system.
- Unsolicited. Unsolicited ECPs are those submitted without a formal written request. Such proposals are not encouraged and will be rejected unless they satisfy one or more of the following criteria:
  - Correct deficiencies.
  - Make significant reduction in manufacturing, operational, or logistics support costs.
  - Prevent slippage in production schedules.
  - Are a value engineering proposal.

Also ECPs are classified in two groups as Class I and Class II. These ECP classes can be explained as follows:

- Class I engineering change proposals: There are two types of Class I engineering change proposals.
  - Preliminary engineering change proposal. A preliminary engineering change proposal is used to determine if a formal engineering change proposal is justified. It is not reviewed by a change control board and cannot be used to authorize a change to a configuration item.
  - Formal engineering change proposal. A formally submitted engineering change proposal which has been engineered, documented, and priced in sufficient detail to support approval.
- Class II engineering change proposals: The ECPs that falling outside Class I ECPs are Class I ECPs. Generally unless otherwise specified by contract, Class II ECPs are not reviewed and approved. Only the contractor has the authority to approve the classification and implementation of the change as Class II.

108.8.3.3 Configuration Status Accounting (CSA)

Objective of CSA report is to provide visibility into the current status of configuration items whether part of a baseline or not. CSA reports also depict the changes made to base-lined configuration items. CSA is the process of creating and organizing the knowledge base necessary for the performance of configuration management. In addition to facilitating configuration management, the purpose of CSA is to provide a highly reliable source of configuration information to support all program/project activities including program management, systems engineering, manufacturing, software development and maintenance, logistic support, modification, and maintenance. CSA includes the following:

- A record of the approved configuration documentation and identification numbers
- The status of proposed changes, deviations, and waivers to the configuration
- The implementation status of approved changes
- The configuration of all units of the configuration item in the operational inventory
- Discrepancies from functional and physical configuration audits

108.8.3.4 Configuration Verification

The objective of verification is to detect and manage all exceptions to configuration policies, processes, and procedures. The configuration verification process includes the following:

- Configuration verification of the initial configuration of a CI and the incorporation of approved engineering changes, to assure that the CI meets its required performance and documented configuration requirements
- Configuration audit of configuration verification records and physical product to validate that a development program has achieved its performance requirements and configuration documentation or the system/CI being audited is consistent with the product meeting the requirements

108.9 Logistics at Disposal Operations Phase

The purpose to dispose a system from inventory is to redistribute, transfer, donate, sell, abandon, or destroy the system. In other words the disposal phase is the process for eliminating the system. At the end of the system's life cycle, the program manager must perform the actions defined in the disposal plan to properly remove the system from the inventory. At the end of its useful life, a system shall be disposed in accordance with all legal and regulatory requirements and policy relating to safety (including explosives safety), security, and the environment.

Before going further on this subject, let's look at the problem from another direction. If the problem is to define the end of life cycle of a system, the definition will predominantly depend on economical, political, and maybe forensic issues. The technical issues may not be as dominant as the other factors. Actually there is no definitive end to a system. Systems normally evolve or transition to the next generation because of changing requirements or improvements in technology.

The disposal activities ensure the orderly termination of the system and preserve the vital information about the system so that some or all of the information may be reactivated in the future, if necessary. Particular emphasis is given to proper preservation of the data processed by the system so that the data is effectively migrated to another system or archived in accordance with applicable records management regulations and policies for potential future access. This point of view is interesting and may be taken into account in some cases. But in this study it is not the case. In the following explanations disposal subject proceeds without regarding information transfer between generations, and it is accepted that with some assumptions end-time definition of a system exists.

In this part disposition options of UAV system and the secondary market alternatives are examined. At the end of the sustainment period, a decision process is taken into account. This process interrogates the discarding method of a system from inventory. This method may be either return the UAV to vendor, to the landfill, or to the secondary market [23].

Actually disposal of a system is an inventory management problem and depends on economic concerns and cost-effective aims. The reasons of disposal or transfer to a secondary market may be listed as follows:

- UAV system does not meet the customers requirements anymore
- To repair the malfunction or defect of a UAV system isn't cost-effective
- The obsolete percentage of material requirement list on the system is relatively high and equivalent components are not available
- Maintaining a UAV system in operation is not cost-effective because the end of systems life cycle is reached

Especially for UAV systems malfunctions and defects are more encountered than piloted aircraft systems. This feature affects not only the maintenance procedures but also the disposal procedures. For that reason the flying part of UAV systems are generally disposed before their life cycle. On the other hand life cycle of ground assets of UAV systems is limited with obsolescence of subsystems. Disposing before life-cycle trend for flying part of UAV systems is more valid for small UAVs than larger ones. In fact disposing large UAVs before their life cycle is not so cost-effective. Nonetheless, repairing and replacing most parts of large UAVs and increasing the periodic maintenance frequency of them are applied methods for lasting the life cycle of UAVs longer.

108.9.1 Disposition Methodologies

Disposition of a system means remove the system from inventory of an organization. The organization may be military, governmental, or nongovernmental. Whole kinds of organizations have an inventory, and inventory removal methods are similar by some means or other. Disposition methods and rules of UAV systems are similar to any other airborne system; the only difference is additional ground assets. Disposition of a UAV system is an economical, political, and managerial decision, and for some cases it can be a strategic decision. For removing a UAV system from inventory, there are basically three methods. These methods are listed as follows:

- *Method 1*: Remove the UAV system and whole its subsystems from inventory for good, and do not operate any reverse logistics processes:
- *Method 2*: Remove the UAV system from the inventory, but don't dispose the whole subsystems. Some subsystems are recycled to the system, in order to reuse in somewhere else in the organization.
- *Method 3*: Remove the UAV system from inventory by selling a secondary market.

All the methods have some advantages and some disadvantages in some ways. Methodology selection process is conducted by assessing many merits into account. Some of these merits are listed as follows:

- The condition of UAV system, in operation or failure
- Technology level of UAV system and its relative condition with the state-of-the-art technology
- Cost efficiency of maintenance
- Reusing case of UAV subsystems
- Operational requirement for the system
- Predetermined life cycle of the UAV system

108.9.2 Life-Cycle Cost Analysis

Disposal decision for a system is given at the beginning of the project with life-cycle cost (LCC) analysis. For this purpose LCC analysis is mentioned under disposal phase. Generally it is carried out in the planning part of a project, but it can be performed in all phases of life cycle. Also LCC analysis can be performed in during sustainment phase. By the way corrective calculations due to usage can be added into LCC analysis. If the LCC analysis is made at the beginning phase of a project, then the inputs of sustainment phase experiences may not be covered. As mentioned before the accident rate of UAV systems is higher than that of piloted aircraft. The source of accidents can be categorized as human, material, or environmental factors. Human causal factors relate to human errors. Material causes being the result of equipment failure and damage as a result of design flaws, component, or system failure such that the system becomes inoperable. Environmental factors include noise, illumination, and weather conditions [24]. If the LCC analysis is carried out in the beginning of the project, the undesirable conditions of UAV system during operations and usage may lead the organization to make the LCC analysis during sustainment phase again.

Before explaining LCC analysis, giving the definition for LCC will be beneficial. Fundamentally LCC is cumulative cost of a product over its life cycle. There are a lot of different definitions for LCC. One short and to the point of them is defined as, "LCC is the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission" [25].

LCC are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced in annual time increments during the project life with consideration for the time value of money. The objective of LCC analysis is to choose the most cost-effective approach from all possible alternatives to achieve the lowest long-term cost of ownership. LCC is an economic model over the project life span. Usually operation, maintenance, and disposal costs exceed all other first costs related with procurement. The best balance among cost elements is achieved when the total LCC is minimized [26].

LCC helps change provincial perspectives for business issues with emphasis on enhancing economic competitiveness by working for the lowest long-term cost of ownership which is not an easy answer to obtain. Consider these typical problems and conflicts observed in most organizations:

- Project engineering wants to minimize capital costs as the only criteria
- Maintenance engineering wants to minimize repair hours as the only criteria
- Production wants to maximize uptime hours as the only criteria
- Reliability engineering wants to avoid failures as the only criteria
- Accounting wants to maximize project net present value as the only criteria
- Shareholders want to increase stockholder wealth as the only criteria [27]

LCC analysis is a collective term comprising many kinds of analysis. These analyses cover reliability-availability-maintainability analysis, economic analysis, and risk analysis. A main objective of the LCC analysis is to quantify the total cost of ownership of a product throughout its full life cycle, which includes research and development, construction, operation and maintenance, and disposal. The predicted LCC is useful information for decision-making in purchasing a product, in optimizing design, in scheduling maintenance, or in planning revamping. LCC analysis may be applied for:

- Evaluation and comparison of alternative design
- Assessment of economic viability of projects/products
- Identification of cost drivers and cost-effective improvements
- Evaluation and comparison of alternative strategies for product use, operation, test, inspection, maintenance, etc.
- Evaluation and comparison of different approaches for replacement, rehabilitation/life extension, or disposal of aging facilities
- Optimal allocation of available funds to activities in a process for product development/improvement
- Assessment of product assurance criteria through verification tests and their trade-offs – long-term financial planning [28]

An LCC analysis procedure has some essential subprocesses. To be mentioned these subprocesses will be helpful for understanding LCC analysis. These subprocesses may be summarized as six basic processes as follows:

- Problems definition
- Cost elements definition
- System modeling
- Data collection
- Cost profile development
- Evaluation [29]

108.10 Future UAV Logistics Trends

108.10.1 Airborne Logistics Support

UAVs will fill in the physical gap between satellites and the manned aircraft in the near future. Some sort of UAVs will access to the stratosphere and stay aloft for weeks, months, or even years without landing. They would accomplish the missions of the satellites such as TV broadcast, and radio communication with more reasonable costs. These UAVs should be designed to tolerate the special environmental conditions in the stratosphere and have the ability to serve for a long period of time without any important intervals requiring any logistics support on the ground. Thus, such UAVs required staying aloft for a long period of time; airborne logistics support will be needed.

Airborne logistics support will be done manned or unmanned aircraft which will have necessary equipment to diagnose the malfunctions and to do periodic tests. They also have the capability to carry enough supply materials such as fuel, oil, and lubricants. How the maintenance will be done will depend on the type of the maintenance requirement. If periodic maintenance such as supplying fuel or doing periodic tests is required, it would be done automatically by the technicians on the ground. But for the malfunctions requiring the replacement of parts, the technicians should be on the airborne logistics support vehicle with required spares.

108.10.2 Power Refueling by Laser

Apart from some solar-powered high-altitude UAVs currently under development, UAVs have to land to have their batteries recharged or fuel cells filled. There are currently some experiments to develop economically viable technology to use lasers to remotely power motors and recharge batteries while UAVs are flying. The concept under development works by turning electricity into laser light which is beamed to a remote receiver on the UAV. This converts the light back into electricity where it can be used to drive a motor or power a battery or payload. If this laser technology matures enough, some type of UAVs can fly and do mission much longer than today.

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