QUALITY ASSURANCE

DURING

SYSTEM/PRODUCT DEVELOPMENT

BY

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I, Richard Wilhelm Schultz, submit this thesis for the degree of Master in Industrial Administration. I claim that this is my original work and that it has not been submitted in this or in a similar form for a degree at any University.

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ABSTRACT

This thesis discusses the need for and requirements of quality assurance during development of systems and products.

Quality Assurance is necessary during the acquisition programme to verify that the deliverable end products and systems satisfy the requirements of the user or client.

No proper guidance is available to the industry on the subject of Quality Assurance during development.

The objective of this thesis is thus to develop a Quality Assurance model for use as a guide for quality assurance planning on each project.

Quality Assurance can however not be discussed without reference to an acquisition programme. An acquisition model based on historic developments in the United States Defence Industry is proposed.

The acquisition model has been structured into destinct events and decision points to make it easy to follow. The thesis provides a consolidated structure which consists of:

- Acquisition Phases
- Baselines
- Milestone decision points

The stepped approach is required to systematically reduce technical, time and cost risks during development.

The proposed quality assurance model is discussed in detail and integrated into the above acquisition model. The quality assurance model consists of the following processes:

- Reviews
- Audits
- Qualifications

The purpose and requirements of the quality assurance processes are discussed in detail and their placing and relationships in the acquisition programme are explained.

Although various aspects of Quality Assurance during development have been discussed in literature, to date, the author has found no attempt to incorporate these into a single model or structure. This thesis presents such a model for use as a guide for Quality Assurance planning on each project. The proposed quality assurance processes can be selected and tailored to suit each individual project.

ABBREVIATIONS

ABL	Allocated Baseline
ADM	Advanced Development Model
CDR	Critical Design Review
CI	Configuration Item
CON	Concept
DEF	Definition
DID	Data Item Description
DOD	Department of Defence
EDM	Engineerring Development Model
EMC	Electromagnetic Compatibility
FBL	Functional Baseline
FCA	Functional Configuration Audit
FMECA	Failure Mode Effect and Criticality Analysis
FSD	Full Scale Development
INDUST	Industrialisation
LCC	Life Cycle Cost
MBL	Manufacturing Baseline
MIL	Military
MIL-SPEC	Military Specification
MIL-STD	Military Standard
MRI	Master Record Index
PBL	Product Baseline
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PM	Production Model
PPM	Pre-Production Model
PROD	Production
PRR	Production Readiness Review
RBL	Requirement Baseline
SDR	System Design Review
SOW	Statement of Work
SRR	System Requirement Review
WBS	Work Breakdown Structure
XDM	Experimental Development Model

QUALITY ASSURANCE DURING SYSTEM/PRODUCT DEVELOPMENT

CHAPTER ONE

INTRODUCTION

Quality Assurance can be defined as all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.(1)

The South African Defence industry has been expanding drastically over the past few years. The political pressures which caused this expansion also demanded adjustment by Industry, from only manufacturing products according to provided product specifications, to also developing systems and products to satisfy user requirements.

The requirements of the South African Defence were thus changed from purchasing manufactured products to acquisition of systems and products. Purchasing requires a proven product specification or other purchasing description as an input. To assure the quality of a purchased item, acceptance according to the product specification is adequate. In most cases purchasing is applicable to off-the-shelf or production items.

Acquisition on the other hand requires a User Requirement Statement as input to the development phase. The output is a product or system which is fully qualified against the User Requirement Statement.

Quality Assurance must form an integral part of the acquisition program. Without Quality Assurance it is not possible to ensure the integrity of the acquisition process. Quality Assurance during the development phases of the acquisition process is necessary to verify that the outputs satisfy the inputs. Without proper verification processes, one may arrive in production with products and systems which are not meeting and satisfying user or customer expectations in terms of stated requirements. This can ruin a company financially.

The credibility of a company can suffer severely in terms of customer confidence to invest in or contract the company in the future.

Very little literature is available on the subject of Quality Assurance during the development phases of the acquisition process to guide the Industry. A guide is therefore required to verify compliance to stated requirements of product and system designs and their manufacturing processes.

The objectives of this document are:

(a) To research literature on the subject of Quality Assurance applicable to development.

(b) To develop a Quality Assurance model for verifying that the outputs of the development process satisfy the inputs.

(c) To provide a concise handbook on Quality Assurance during system/product development for South African industry, with special reference to the military environment. Such a document is not available. This document is aimed to fill that gap. This document can be used as a guide for Quality Assurance planning on each project.

(d) To introduce the theory of the acquisition process and its relation to Quality Assurance verification processes.

Although the material in this document is primarily orientated towards the development of products and systems for the Defence Force of South Africa, the information presented has a much broader application in the commercial world. Tailoring can be applied to suit each project and the environment.

The topics discussed are in general not new, but consolidation and integration of these theories provide the Quality Assurance verification model.

Chapter two defines the basic acquisition model for development. The different phases and development models of the acquisition process are outlined in this chapter. The basics of baseline management are also described in this chapter. Baselines are the basis for development inputs and outputs per phase and are important ingredients for the Quality Assurance verification process.

Chapter three gives detailed descriptions of the different reviews and where they fit into the acquisition process.

Chapter four gives detailed descriptions of the different audits and where they fit into the acquisition process.

Chapter five gives an extensive overview of the different types of qualifications and their relation to each other in the acquisition process.

Chapter six gives a complete quality assurance verification model with all the previously described elements fully integrated.

CHAPTER TWO

THE ACQUISITION MODEL

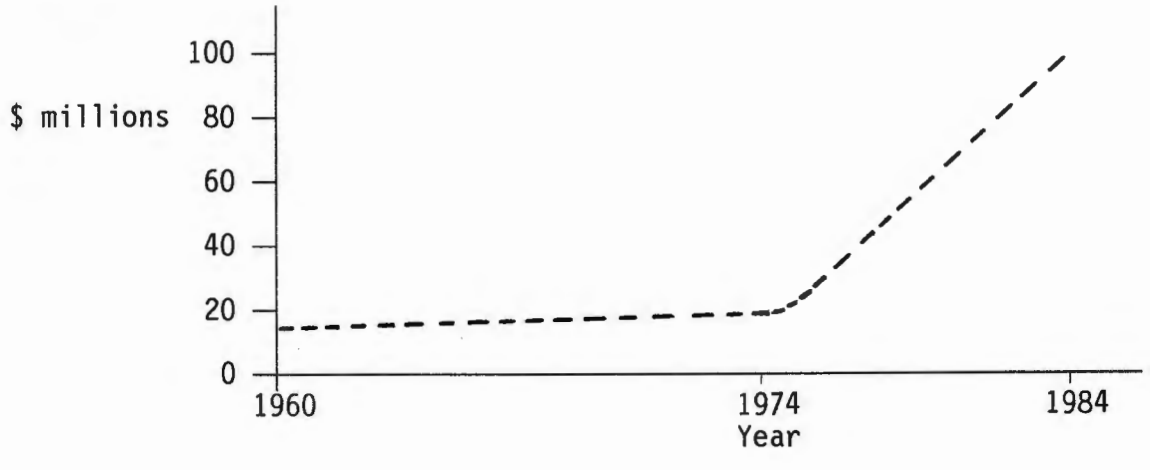
It is not possible to introduce a Quality Assurance model without a good understanding of the development processes and principles of baseline management. Quality Assurance during system and product development must therefore be based on an acquisition model.

The acquisition process is a sequence of logical steps in the acquisition of a system or product.(2)

The need to structure the acquisition process into a sequence of distinct events has become very important and necessary because of the size and complexity of projects in recent years. Figure 1 illustrates what has happened to one construction company in terms of project size.

FIGURE 1

Average project size capability for a construction company, 1960-84(3)



The main objective of the acquisition process is to satisfy the requirements of the user.(4) The requirements of the user should be defined in terms of a User Requirement Statement and these requirements are satisfied by providing a qualified system or product to the user.

The acquisition process is normally divided into five phases to enhance management effectiveness. These phases should be tailored to fit each acquisition to minimize acquisition time and life cycle costs. Tailoring is applied to meet the urgency of the need and degree of technical risk involved.(5) Milestone decisions that are not delegated to the program manager are known as milestones 0, 1, 2, and 3 and form the division between successive phases. By making the milestone decision that the next phase may proceed and identifying the specific limitations, the applicable acquisition baseline is confirmed.(6)

Typical acquisition phases, milestone decisions and acquisition baselines are indicated in Figure 2. The typical acquisition program is illustrated in Figure 3.

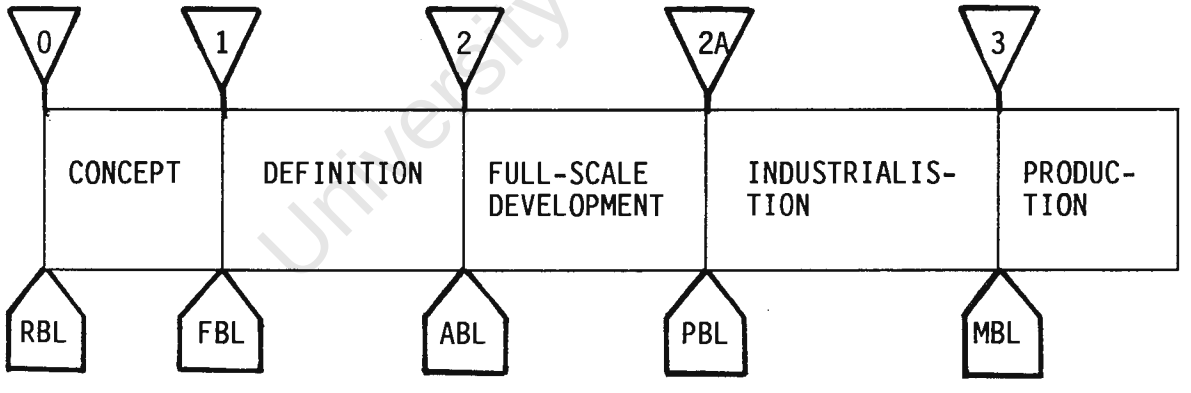
FIGURE 2

Typical acquisition phases, milestone decisions and acquisition baselines.(7)

STARTING POINT BASELINE	MILESTONE DECISION	SUCCESSIVE PHASE
Requirement Baseline (RBL)	0	Concept (CON)
Functional Baseline (FBL)	1	Definition (DEF)
Allocated Baseline (ABL)	2	Full-scale Development (FSD)
Product Baseline (PBL)	2A	Industrialisation (INDUST)
Manufacturing Baseline (MBL)	3	Production (PROD.)

FIGURE 3

A typical acquisition program(8)



The various phases, milestones and baselines are discussed in detail under the appropriate headings.

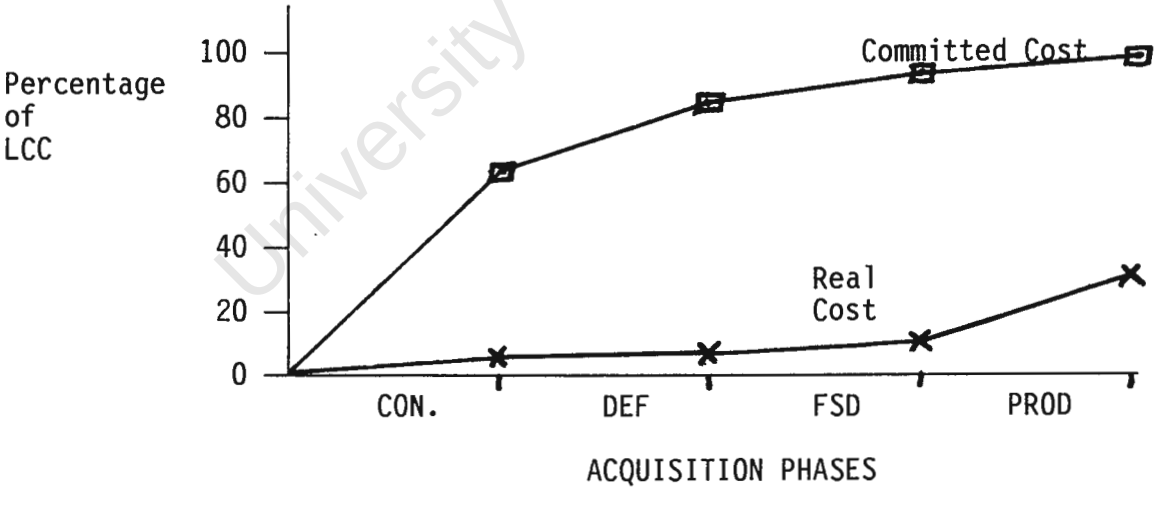
2.1 Acquisition Phases

The acquisition of systems and products should be performed in successive distinct phases established to facilitate adequate management control over the expenditure of funds and to ensure timely availability of required systems and products. Figures 2 and 3 illustrate the sequence and the interrelationships between phases of the system acquisition process.

The early phases of the acquisition process are very important to control the Life Cycle Costs (LCC) of a system or product and should receive careful attention. Early decisions have the greatest impact on life cycle costs and are illustrated in Figure 4. The typical real cost incurred are also shown in this figure.

FIGURE 4

Control LCC in early acquisition phases[9]



Tailoring can be applied to select the necessary phases for each project. When logical, phases could be skipped or combined. The following is a description of the different phases.

2.1.1 Concept Phase

The input to the concept phase is the Requirement Baseline which should contain the User Requirement Statement. The Requirement Statement should include no more than the minimal technical objectives which can be anticipated realistically to be achievable within a projected time and cost limitations.

The main objective during this phase is to transform broadly defined operational and functional needs directly related to a mission, into a system specification which defines the functional requirements of the system. During this phase alternative concepts, their characteristics, i.e. estimated operational, schedule, procurement, cost and support parameters, and their configurations are evaluated.

To narrow down the number of alternatives, exploratory development and preliminary design may be required. The other activities during this phase should include

- Feasibility and risk assessment
- Production feasibility assessment
- Logistic support estimation
- Trade-off studies
- Cost-effectiveness studies.

The final output of the concept phase is the Functional Baseline of the recommended alternative.

Exploratory development models (XDM) are used to systematically reduce uncertainties.

An exploratory development model is an item used for experimentation or tests to investigate or evaluate the feasibility and practicality of a concept, in rough experimental form, without regard to the eventual overall fit or final form.[10] How many models to use for a given project is determined by the need to systematically reduce uncertainty.

2.1.2 Definition Phase

The input to the definition phase is the Functional Baseline which should contain the system specification. The system specification should contain the technical and mission requirements and allocation of system functions with their interfaces.

The definition phase is entered into when sufficient demonstration data has been evaluated to indicate justification for further development of the design and prototype models.[11] At this point of the development program, more complete knowledge of the applicable technologies, to solve the technical objectives, should be available.

The main objective of the definition phase is to validate and refine the choice of alternatives and select the most promising approach. The functional requirements in the system specification are allocated to configuration items (CI) which are described in terms of development specifications.

Characteristics of performance, cost and schedule should be validated and refined through extensive study and analysis, development and prototype testing. Hardware models are developed, tested and evaluated to demonstrate adequate risk reduction of high risk items. Assurance should be provided in this phase that problems which must be solved in the full-scale development phase are within demonstrated state of art.

Attention should also be given to cost effectiveness, trade-off studies, logistics support requirements, risk identification, producability etc.

The final output of the definition phase is the Allocated Baseline which contains the different item development specifications.

Advanced development models (ADM) are used to reduce risk. An advanced development model is an item used for experimentation or tests to

a) demonstrate the technical feasibility of a design,

b) determine its ability to meet existing performance requirements,

c) secure engineering data for use in further development and, where appropriate,

d) establish the technical requirements for contract definition.

Dependent upon the complexity of the item and the technological factors involved, it may be necessary to produce several successive models, to achieve objectives. The final advanced development model approaches the required form factor and employs standard parts. Serious consideration should be given to requirements such as reliability, maintainability, human factors and environmental conditions.(12)

2.1.3 Full-scale Development Phase

The input to the full-scale development phase is the Allocated Baseline, which should contain the relevant item development specifications. Each configuration item should have a development specification. Each item should undergo development in separate development programs. The development specification should contain sufficient performance characteristics to enable development of the configuration item into a detail design for production.

At this stage in the acquisition programme, a large-scale commitment of resources must be made by the procuring activity. A commitment to the full-scale development phase usually implies a commitment for future production procurement for fulfilling an approved mission.[13] It is therefore very important to make sure that the Allocated Baseline contains the appropriate documentation and that the development specifications are properly derived from the system specification.

The development specifications are used as basis to perform the following activities during the full-scale development phase:

- Preliminary design
- Detail design
- Development Test and evaluation
- Initial operational test and evaluation

The final output of the full-scale development is the Product Baseline, which should contain product specifications, material specifications and process specifications. These specifications should contain the detail design of the products. This set of documents provides a technical description of the products. The technical discription consists of physical characteristics and functional characteristics.

Engineering development models (EDM) are used for test and evaluation of the product designs. An engineering development model is an item used in tests to determine tactical suitability for use in real or simulated environments for which the item was designed. It closely approximates an initial production design, has the required form, employs standard parts and meets the standard requirements such as reliability, maintainability, human factors, environmental conditions, etc.[14]

2.1.4 Industrialisation Phase

The input to the industrialisation phase is the Product Baseline, which should contain the relevant product specifications, material specifications and process specifications. Each configuration item should have a set of the specifications.

Industrialisation denotes the actions or phases during which the manufacturing processes, equipment, facilities and documentation are fully developed and put to the test. These actions include limited design modifications to facilitate production.(15)

Industrialisation may form an integral part of the Full-scale development phase when the manufacturer is also the developer and when the risk is not too high to authorise both full-scale development and industrialisation simultaneously. When development of the manufacturing process, however, requires considerable resources and the risk is too high, then it is meaningful to handle industrialisation separately. Manufacturing under licence also requires that industrialisation is done seperately.

During this phase attention is given to manufacturing process design. Facilities and equipment are designed and commissioned. These may include buildings, fixtures, machinery, tools, jigs, gauges, measuring equipment and test equipment.

This final output of the industrialisation phase is the Manufacturing Baseline, which shall contain the detailed item "Build according to" information in the form of engineering drawings, work instructions and manufacturing process specifications.

Pre-production models (PPM) are used to test and evaluate the manufacturing process.

The pre-production model is an item suitable for complete evaluation of form, fit and performance. It is in final form in all respects, employs standard parts and is completely representative of final equipment.(16)

Pre-production lots or batches of the configuration items are built to test and evaluate the manufacturing process.

2.1.5 Production Phase

The input to the production phase is the Manufacturing Baseline which should contain the product specifications, material specifications, process specifications, design drawings and work instructions.

The required products and systems are produced during this phase and delivered to the client for use. The necessary training aids, spares and logistic support are also provided in this phase. Final operational test and evaluation on production models are conducted early in this phase, to detect and correct unacceptable deficiencies. the production model (PM) is an item in its final form of final production design made by production tools, jigs, fixtures and methods. It employs standard parts.(17)

2.2 Baselines

A baseline represents the quality levels to be achieved as confirmed by a set of documents which consolidates and documents the results of a preceding phase. The Baseline is approved and confirmed by the authorised management and serves as inputs, constraints and the starting point for the subsequent phase.(18)

The quality requirements applicable to each baseline should be defined for each acquisition program.

A set of documents is frozen at a specific time and serves as a formal departure point for control of future changes in performance and design of the system or product. Without changes, development is impossible, but these changes must be managed or else there is no control over the development process. Configuration management is oriented toward change management.(19)

Baselines are the basic requirements from which contract costs are determined. Once defined, changes in these requirements are formally approved and documented to provide an equitable way to adjust contract costs.(20)

Changes to baselines are unavoidable during a development contract. The change process must, however, be controlled.(21) Changes may include the following:

- use of more/less management reserves
- rescheduling of work
- addition or removal of work
- shifting of work
- shifting of budgets to other organisational elements/cost centres
- redistribution of resources
- technical changes which influence form, fit or function
- technical changes which do not influence form, fit or function
- changes in contract costs.

Baselines provide management control over changes and ensure that a system or product can be defined progressively in more detail until the original objective, to satisfy the user requirement, is met.

Baselines provide proper records of previous work and decisions, and provide clear objectives for a subsequent step in the acquisition program.

All descriptions of baselines of a system, or configuration items, used to state product performance and design requirements, must be contained in specifications.(22)

MIL-STD-490A provides the criteria for all specifications to be developed in the different acquisition phases. The format, content and use of the different specifications recognise the principles of configuration management. The different specifications recognise the specific periods of development and design evolution and are organised for progressive definition of physical and functional requirements and change control.

The specifications are used to relate the performance requirements to design drawings.

The baseline standards applicable to each baseline should be selected by the Programme Manager and should be tailored to suit each specific acquisition program.

The different baselines, as identified in Figure 1 and 2, are now discussed in more detail.

2.2.1 Requirement baseline (RBL)

The Requirement Baseline describes the requirement the system has to satisfy.(23)

The following are standards which should be applicable to the baseline:(24)

a) A Staff Requirement is available. This document should include:

- A user requirements statement, which includes operational and technical requirements, logistic support requirements, a user value system and other general user constraints;

b) A Program Strategy exists which incorporates the following strategic plans:

- The Industrial Plan which determines the choice and prescription of contractors, type of contract, the availability of facilities, etc.

- The Technology Plan which determines the choice and contraints of technologies in the program, thus impacting the concept solutions.

- The Marketing Plan which determines the extent to which the system or product is to be marketed, with implications to technical requirements (including supportability and standardisation), concept solutions, acquisition costs, pricing, schedule, etc.

- The Finance Plan which determines the affordability of and the methods of financing the program.

- The Manpower Plan which describes the viability of the program in terms of the availability of skilled manpower.

- The Security Plan which determines security requirements and how security is assured throughout the program.

c) A Program Plan exists which includes:

- A Program budget.

- Program milestones.

- Program Statement of Work (SOW) and Work Breakdown Structure (WBS).

- A program risk analysis (cost, schedule and technical).

d) A Programme Manager is appointed, whose authority and responsibility is clearly stated.

e) A Master Record Index (MRI) exists, listing all applicable baseline documentation.

2.2.2 Functional baseline (FBL)

The Functional Baseline describes the system's functional or performance requirements that will satisfy the requirement.(25)

The following are standards which should be applicable to the baseline:(26)

a) A system specification (may be a development specification for a single product) exists, according to MIL-STD-490A, and is under configuration control. Interfaces are identified. The system specification has been approved by all relevant parties concerned.

b) The Program Strategy has been updated.

c) The Program Plan has been updated.

d) Risk identification, ranking, avoidance/reduction and control has been practiced and a risk avoidance/reduction plan exists.

e) Trade-off studies have been conducted, using the user and program value systems, in the choice of the approach/solution, and are evident in design reports. These design reports provide sufficient demonstration that the system specification is adequate and cost-effective in satisfying user requirements.

f) Speciality Discipline Areas have received adequate attention as evident in study reports, and requirements are integrated in the system specification. This includes, for example, logistics, reliability, availability, maintainability, ergonomics, vulnerability, electromagnetic compatibility (EMC), environmental conditions, failure mode effect and criticality analysis (FMECA), life cycle cost analysis.

g) A project management system is implemented.

h) The following plans exist:

- System Engineering Management Plan;

- Technical Performance Management Plan;

- Configuration Management Plan.

i) The Master Record Index (MRI) is updated.

The System Specification states the technical and mission requirements for a system as an entity, allocates requirements to functional areas, documents design constraints, and defines the interfaces between or among the functional areas.(27)

The first version of the System Specification contains the parameters which were developed during the concept phase. The first version establishes the general requirements of the system that is to be further defined and finalised in the definition phase. The final system specification forms the basis for the development and design of the configuration items. The system specification shall be prepared in accordance with the format and content of MIL-STD-490A.(28)

2.2.3 Allocated baseline (ABL)

The Allocated Baseline describes the performance requirements of the different elements of the system.[29]

The Allocated Baseline contains item "design according to" information in the form of a development specification and interface specifications.

The following are standards which should be applicable to the baseline:[30]

a) An updated system specification exists, and is under configuration control.

b) A development specification exists for each configuration item in the system and is under configuration control.

c) Interface control specifications exist for each interface between configuration items and are under configuration control.

d) The development specifications, together with the interface control specifications, provide an adequate basis for contracting.

e) The program strategy has been updated.

f) Risks for full-scale development have been identified and specific risk reduction strategies exist.

g) The program plan has been updated.

h) The following plans exist:

- Systems engineering management plan;
- Technical performance management plan;
- Quality program plan;

- Test and evaluation master plan;

- Configuration management plan

i) Allocation of requirements from the FBL system specification is confirmed in a design review.

j) A specification tree exists, listing all major specifications hierarchically.

k) The project management system is successfully applied and provides adequate information for decision making.

l) The Master Record Index (MRI) is updated.

The development specification states the requirements for the design or engineering development of a product during the development period.(31)

The development specification should describe the performance characteristics which the detail design of a configuration item must achieve after development. The development specification may be kept alive during production when it is required to retain a complete statement of performance requirements for the configuration item.

The development specification shall be prepared in accordance with the format and content of MIL-STD-490A.(32)

2.2.4 Product baseline (PBL)

The Product Baseline describes the detailed form, fit and function of the item, including the information necessary to operate and support the item during its lifetime.(33)

The product baseline contains "build according to" information, in the form of a product specification. It also contains operating manuals and support documents.

Material specifications and process specifications are referenced in the product specification when applicable.

The following are standards which should be applicable to the baseline:(34)

a) The system or product is defined in terms of a system specification, product specifications and interface control specifications.

b) All specifications are complete, are referenced by the Master Record Index (MRI), and are under configuration control.

c) Fit, form, function and availability are formally qualified, and satisfy the user requirements as confirmed in a design review.

d) The program strategy has been updated.

e) Industrialised risks have been identified and specific risk reduction strategies exist.

f) The program plan has been updated and reflects risk reduction strategies during industrialisation.

g) The following plans have been updated:

- Systems engineering management plan:
- Technical performance management plan;
- Quality program plan;
- Test and evaluation master plan;
- Configuration management plan.

h) A audit has verified that the system and each product performance complies with the ABL.

The product specifications are applicable to any configuration item below the system level, and may be oriented toward procurement of a product through specification of primarily functional (performance) requirements or primarily fabrication (detailed design) requirements.(35)

The product function specification contains complete performance requirements and interface and interchangeability characteristics. Complete form, fit and function are included in this specification.

The product fabrication specification contains the detail design in terms of drawings and the perform requirements necessary to assure proper fabrication.

Material specifications are applicable to raw material (chemical compound), mixtures (cleaning agents, paints), or semi-fabricated material (electrical cable, copper tubing) which are used in the fabrication of product.(36)

Process specifications are applicable to a service which is performed on a product or material. Examples of processes are: heat treatment, welding, plating, packing, microfilming, marking etc. Process specifications cover manufacturing techniques which require a specific procedure in order that a satisfactory result may be achieved.(37)

Interface specifications contain the physical and functional characteristics which affect the compatibility between systems or configuration items.

2.2.5 Manufacturing baseline (MBL)

The manufacturing baseline contains the detailed item "build according to" information in the form of drawings and work instructions.(38)

Product specifications, material specifications, operating manuals and support documentation are also part of this baseline to serve as input to the production phase.

The following are standards which should be applicable to the baseline:(39)

a) Manufacturing processes are fully developed, specified and qualified, and form a basis for production. Qualification is confirmed in a design review.

b) A audit has been conducted to determine compliance of a production item to its product specification.

c) An updated program strategy exists.

d) An updated program plan exists which reflects production, delivery, commissioning, and maintenance plans.

e) The following plans have been updated:

- Quality program plan;
- Test and evaluation master plan;
- Configuration management plan;
- Marketing plan;
- Production plan;

f) Production risks have been identified and specific risk reduction strategies exist.

g) Maintenance and acceptance specifications for repaired systems exist where appropriate.

h) An acceptable unit production price is available.

i) The Master Record Index (MRI) is updated.

2.3 Milestone decisions

The Milestones applicable to the acquistion model are as indicated in Figure 3 and form the devision between successive acquisition phases.

These milestone decisions are not delegated to the programme manager, but are taken by a Technical Review Board.(40)

Management are receiving reports from the programme manager which contain results of the preceding phases and the planning of the next phases. This information is evaluated in programme reviews for the indicated milestone decisions.

By making the milestone decision that the next phase may proceed and by indentifying the specific limitations, the applicable acquisition baseline is confirmed.(41)

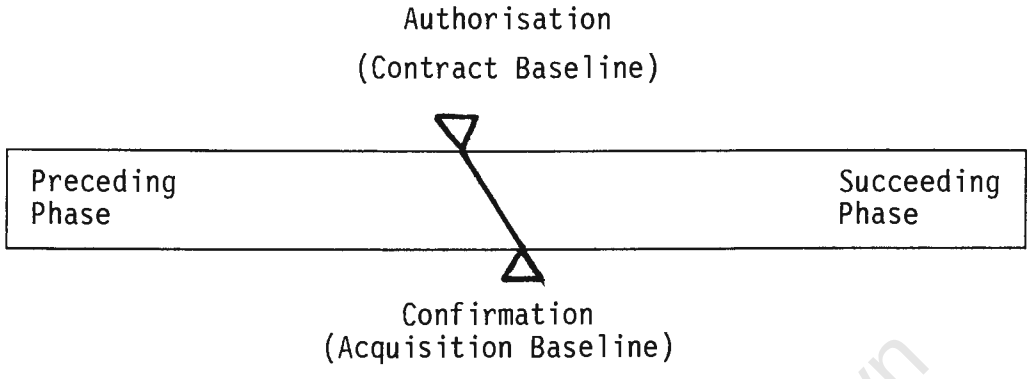
The milestone reports are only used in support of the programme review concerned and in no way take the place of an acquisition baseline. The milestone report 0 is known as the programme strategy and contains both the implementation strategy and the broad draft solutions applicable to the program. The program strategy is updated for each program review.(42)

Overlapping may occur between successive phases and authorisation to commence with the next phase can be granted on the basis of provisional information of the incompleted phase. This authorisation creates a contract baseline. Confirmation to proceed with the next phase creates an acquisition baseline and is based on complete information, as the preceding phase must be fully completed. This is situation is detailed in figure 5.

The commencement of work in the succeeding phase without completion of the preceding phase may be necessary for various reasons eg. purchase of long lead time items and strategic materials. Risks are increased in this approach and should be identified and highlighted.

FIGURE 5

Authorisation and confirmation to proceed with next phase.[43]



The acquisition program can be classified as cardinal, critical, important or routine by senior management. The criteria which may be used could include:[44]

- The magnitude of risks involved in the acquisition programme.
- The urgency of the requirement.
- The political profile of the acquisition programme.
- The estimated costs of development or production.
- The national strategic importance of the program.

The Technical Review Board confirm that each baseline in the programme has been reached and comply with the defined requirements and standards. The laid down standards applicable to each baseline were identified in 2.2.

The Technical Review Board is composed of different levels of management depending on the classification of the programme.

The following guidelines may be used for the different programmes:

a) Cardinal Programme:
   Executive General Manager (chairman)
   Senior General Managers
   Programme Manager
   Quality Assurance Manager

b) Critical Programme:
   Senior General Manager (chairman)
   General or Assistent General Managers
   Programme Manager
   Quality Assurance Manager

c) Important Programme:
   General or Assistent General Manager (chairman)
   Divisional/Department Managers
   Programme Manager
   Quality Assurance Manager.

d) Routine Programme:
   Divisional/Department Manager (chairman)
   Programme Manager
   Quality Assurance representative.

Other people may be coopted by the chairman as necessary.

Authorisation committees may be used to authorise the commencement of the next phase. Authorisation is normally granted after confirmation of the baseline by the technical review board. Authorisation to proceed with the next phase may however be granted before confirmation of the baseline as explained previously. Authorisation creates a contract baseline. The activities of the authorisation committee is mostly concerned with legal and financial aspects of the contract.

The composition of the authorisation committees is also based on different management levels and the classification of the programme.

The same guidelines as for the Technical Review Boards may be applicable, with the inclusion of persons from.

- Legal administration
- Finance
- Security
- Procurement

2.4 A critical appraisal of the acquisition model

The acquisition model is based on standards and specifications of the United States Defence force and the Armaments Corporation of South Africa.

History has shown that a sequence of steps are required to avoid failure.

In the 1950's shortcuts were taken to shorten time scales. Development and Production of products and systems were done in parallel. Production stopped and started continuously to fix problems. This resulted in:

- Long time delays and great cost escalations.
- The wrong system selection because alternative concepts were not considered.
- Invalid time/cost estimates.

The acquisition phases applicable in the 1950's were limited to:

- Planning phase
- Development phase
- Production phase

Mr Mcnamara, United States Secretary of Defence, introduced the following phases in 1964:

- Concept phase
- Contract Definition phase
- Acquisition phase

Acquisition programmes still failed during the 1960's because of inadequate phases. An example was the B-70 Aircraft Bomber project in 1967 to 1968. Experimentation ended after spending $ B 1,5, because the mission concept was not properly analysed and subjected to cost-effectiveness scrutiny.

Mr Packard, United States Secretary of Defence, introduced the Acquisition policy in 1971, after finding that seven major systems on average costed 79 % more and development time was 32 % longer than originally planned. Five phases were introduced:

- Concept
- Validation (Definition)
- Full scale Development
- Production
- Deployment

Since then many succesfull projects were run. An example was the fighter aircraft missile AIM-120 during 1976 to 1986. This missile was an improvement with a factor of at least two over the AIM-7 sparrow missile. This success story was accomplished because the stepped approach, ie. different phases, was followed to systematically reduce risk.

The Armaments Corporation of South Africa implemented the acquisition policy during 1988.

My experience of thirteen years in the South African arms industry has learned that many projects failed due to a lack of a systematic approach. Life cycle costs of many systems were found to be unacceptable only after many years of production.

Since following the Acquisition process, less problems have been experienced with cost overruns and late deliveries. Cost overruns of 100 % were not uncommon a few years back. In the last couple of years cost overruns were limited to an average of approximately 20 %. This is a very significant improvement. Time schedule overruns were reduced from approximately 70 % to approximately 15 %. These figures are based on the projects I have managed as a project and Programme Manager.

Although, the acquisition programme is relatively new to our industry, it has already been shown worth while. I foresee more improvement in the near future, as we are still on the learning curve.

The main concern during development is to systematically reduce the technical, time and cost risk. This can only be achieved via logical steps and decision points at regular intervals during the acquisition programme. The acquisition model provides a proper structure to achieve this.

The early phases of the acquisition programme are very important because decisions have such a great impact on life cycle costs. figure 4 illustrates that approximately 65 % and 85 % of the life cycle costs for a system or product are committed at the end of the concept and definition phases respectively.

I have choosen the model, because it has a success record of more than 15 years and because no better structured development model could be found in the literature.

I have structured the model into the distinct events and decision points to make it easy to follow. The literature at my disposal did not provide a consolidated structure. The structure consists of:

- Acquisition phases
- Baselines
- Milestones

The model has been designed for complex systems, eg. aircraft, main battle tanks, armoured cars etc, but can be tailored to suit any project. The risk involved should be considered when selecting the appropriate phases, baselines and decision milestones.

The model can be applied to one-off construction projects eg. bridge, building, ship etc, as well. The industrialisation and production phases should then not be selected as part of the programme. The system or product is in this case designed and built during the full scale development phase. Commissioning of the system or product is done at the end of the same phase.

The model is thus applicable to any type of project and tailored to suit the purpose.

CHAPTER THREE

REVIEWS

One of the Quality Assurance actions which should be applied to verify that outputs of the acquisition process meet the input requirement are called reviews.

Reviews provide visibility and technical understanding to ensure that the system or product design is in agreement with the stated operational requirements.

The reviews are also known as design reviews and are carried out in order to determine and evaluate the progress which is made during a given phase of a acquisition programme. The aim of a design review is to ensure that the approach and choices which are proposed are in accordance with the requirements of the relevant baseline.(45)

Design reviews are selected for each acquisition phase and each review can consist of a series of meetings. Each review may occur incrementally.

The achievements under review normally include the following aspects:

- Performance
- Effectiveness
- Availability
- Costs

The baseline documents under review are released for further action after the design review. The release of the documents takes place by means of acceptance thereof. Action plans are also implemented as a result of the review.

Tailoring should be applied to select the types, time and requirements of reviews. Each project has a different need and tailoring is of utmost importance to avoid unneccessary costs and time delays. Selection should be based on the risks involved.

The function of design reviews is to:[46]

- ensure a higher probability level of design compliance.

- ensure a formal check or audit of the proposed design, with respect to the set requirements.

- provide all participating organisations with a common base in that they serve as a discussion platform.

- provide an opportunity for assuring formally that the interface requirements are being met and that the elements of the user system are compatible.

- provide a formal record of design decisions that have been taken, for future reference.

Design reviews should be conducted at different levels, i.e. programme level and operational level.

Programme reviews should be scheduled for at least the end of each acquisition phase of a programme.

The following design reviews are normally required, but are not limited to these:[47]

- System Requirement Review (SRR)

- System Design Review (SDR)

- Preliminary Design Review (PDR)

- Critical Design Review (CDR)

- Production Readiness Review (PRR)

3.1 General requirements of a review

The contractor should be responsible to conduct the review unless else stipulated in the contract. The contractor should ensure that the appropriate sub-contractors and suppliers are involved when conducting the review.

The contractor should provide the necessary facility, resources and material to perform the review.

The following items may be included:(48)

a) Meeting agenda/plans

b) Conference room(s)

c) Applicable system engineering data, specifications, drawings, manuals, schedules and design and test data.

d) Speciality study results

e) Trade-off study results

f) Risk analysis results

g) Mockups, in-process hardware, and finished hardware

h) Test methods and data

i) Meeting minutes

The contractor should arrange the reviews in consonance with the programme schedule in sufficient advance to allow adequate preparation for the meeting by both the contractor and the procuring activity. The procuring activity should serve as co-chairman.

The procuring activity should approve/disapprove the minutes of the meeting.

The most important outputs of a review are a list of corrective actions with responsibilities and completion dates allocated.

The following are some directions for documents which are used:

- DID DI-A-3029: Design review Agenda

- DID DI-E-5423: Design Review Data Package

- DID DI-E-3118: Design Review Minutes

3.2 System requirements review (SRR)

The objective of the system requirements review is to ascertain the adequacy of the contractor's efforts in defining system requirements.(49)

The system requirements review is normally conducted during the concept phase. The engineering management activities and the preliminary functional baseline (FBL) is reviewed in order to verify that the mission requirements have been fully met.(50)

The output of the concept phase is evaluated to determine compliance with the input. This verification process compare the system specification with the user requirement statement. In order to establish that the system specification meet the user requirement statement, results of the concept phase should be reviewed.

Representative items to be reviewed include the results of the following (as appropriate):(51)

a) System engineering process which include:

- Mission and requirement analysis

- Functional analysis

- Preliminary requirements allocation

- Synthesis

- etc.

b) Cost-effectiveness studies

c) Trade-off studies

d) Engineering speciality studies which include:

- Reliability analysis

- Maintainability analysis

- Integration

- Electromagnetic compatibility

- Logistic support analysis

- etc.

e) Drafts of specifications

f) Configuration management and system engineering management plans.

g) Technical performance measurement planning.

h) Identification, prioritizing, reduction and control of technical, cost and schedule risks.

Detailed requirements are available in MIL-STD-1521A Appendix A.

The team for conducting the review may include the following:

- Contractor Programme/Project Manager (Chairman)
- Procuring Agency Programme Manager (Co-chairman)
- Contractor System Engineer(s)
- Contractor Quality Assurance representative
- Sub-contractor Programme Manager(s)

Other people may be coopted as necessary.

3.3 System design review (SDR)

The system design review should be conducted to evaluate the optimization, traceability, correlation, completeness, and the risk of the allocated requirements, including the corresponding test requirements in fulfilling the system requirements (the functional configuration baseline.)(52)

The system design review is normally conducted during the definition phase. The allocated baseline (ABL) is established after this review.

The output of the definition phase is evaluated to determine compliance with the input of functional baseline (FBL).

A technical understanding should be reached on the validity and degree of completeness of the following information:(53)

a) System specification
b) Development specification(s)

This review takes place after definition of the system characteristics and identification of the configuration items.

The aim of the SDR is to ensure:(54)

- The system specification is adequate and cost effective in terms of satisfying the mission requirements.

- The allocated baseline (ABL) is complete and optimal.

- Technical risks are identified, ordered, avoided and reduced.

- Reliability and maintainability requirements are addressed in full.

The SDR should include a review of the following items, as appropriate:(55)

a) System engineering management activities.

b) Results of significant trade-off studies.

c) Updated design requirements for operations/maintenance functions and items.

d) Updated requirements for manufacturing methods and processes.

e) Updated operations/maintenance requirements for facilities.

f) Updated requirements for operations/maintenance personnel and training.

g) Specific evaluations eg. design feasibility, cost effectiveness, value engineering, "off-the-shelf" standard parts, capabilities of selected configurations, etc.

h) System and development specifications for format, content, technical adequacy, and completeness.

i) System and item design's inter-action with user environment.

j) Maintenance functions developed are valid, feasible and understood.

k) Manufacturing eg. Production feasibility and risk analysis, production capability assessment etc.

Detailed requirements are available in MIL-STD-1521A Appendix B.

The team for conducting the review may include the following:

- Contractor Programme/Project manager (Chairman)
- Procuring Agency Programme Manager (Co-chairman)
- Contractor System Engineer(s)
- Contractor Design Engineer(s)
- Contractor Quality Assurance representative
- Sub-contractor Programme Manager(s)
- Contractor manufacturing representative.

Other people may be coopted as necessary.

3.4 Preliminary design review (PDR)

The preliminary design review should be a formal technical review of the basic design approach for a configuration item or for a functionally related group of configuration items. It shall be held after the development specification(s) is available and the accomplishment of preliminary design efforts, but prior to start of detailed design.(56)

The PDR is normally conducted during the full-scale development phase when a preliminary design is available.

The review is held for each CI in order to:[57]

- Evaluate progress, technical compliance and risk, as well as to evaluate the progress of the design process.

- Establish the compatibility of the selected design approach with the development specification (allocated configuration identification.)

- Establish the existence and compatibility of the different interfaces between CI's.

The following should be reviewed:[58]

a) General CI design

b) Electrical, mechanical and logical design

c) Support equipment design

d) Electromagnetic compatibility

e) Design reliability

f) Design maintainability

g) Human factors

h) System safety

i) Natural environment

j) Equipment and parts standardisation

k) Value engineering

l) Transportability

m) Test

n) Maintenance and maintenance data

o) Spares

p) Packaging

q) Technical manuals

r) Design producibility and manufacturing

Detailed requirements are available in MIL-STD-1521A Appendix C.

The team for conducting the review should be similar to the system design review team.

3.5 Critical design review (CDR)

The critical design review should be conducted on each configuration item prior to design release to insure that the detail design solutions as reflected in the draft product specification and engineering drawings, satisfy the performance requirements established by the development specification.(59)

The CDR is normally conducted during the full-scale development phase after the detail design is available.

The review is held for each CI in order to:[60]

- Establish whether the detail design satisfies the requirements of the development specification and the allocated configuration identification.

- Confirm the compatibility of the design with other CI's.

- Evaluate producibility

- Evaluate risk areas (technical, schedule, cost)

By the time this review takes place, all development and design activities have been completed.

The following shall be reviewed:[61]

a) General CI design

b) Support equipment design

c) Electromagnetic compatibility

d) Design maintainability

f) Human factors

g) System safety

h) Natural environment

i) Equipment and parts standardisation

j) Value engineering

k) Transportability

l) Test

m) Maintenance and maintenance data

n) Spare parts

o) Packaging

p) Design producibility and manufacturing

Detailed requirements are available in MIL-STD-1521A Appendix D.

The team for conducting the review may be similar to the system design review team. More emphasis should however be placed on contributions and participation of design engineers and manufacturing representatives.

3.6 Production readiness review (PRR)

The production readiness review is intended to determine the completeness of the specific actions which must be satisfactorily accomplished prior to executing a production go-ahead decision.(62)

The PRR is normally conducted during the industrialisation phase. If no industrialiation phase is performed, because of manufacturing process design being done in parallel with product design then this review takes place during the full-scale development phase.

The objective of a PRR is to verify that the production design, planning, and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria.(63)

The production design is evaluated for completeness and producibility, and the managerial and physical preparations necessary for initiating and sustaining a viable production effort is reviewed.

The extent of conformance to prescribed conditions for manufacture depends on the point in time the review is made and whether the review is in support of a limited or full production release decision. A review could be applicable just prior to pre-production during the industrialisation phase and at the end of the industrialisation phase prior to the production phase.

The following items may be included in the review:[64]

a) Product design:

- Producibility risk
- Activity of design changes
- Standardisation of parts
- Critical and scarce materials
- Alternatives for critical and scarce materials
- Production cost projections
- Completeness of data package

b) Industrial resources:

- Plant facilities, production equipment, test equipment and tooling.
- Personnel (skill, training etc.)

c) Production engineering and planning:

- Comprehensiveness of production plan
- Production schedules
- Nature and sequence of manufacturing methods and processes.
- Value engineering analysis
- Alternative production approaches
- Explicity of drawings, standards and manufacturing instructions
- Configuration management practices.
- Responsibility for production
- Management information system to provide the status of production.

d) Materials and purchased parts:

- Bill of materials
- "Make-or-buy" determinations
- Long lead time items
- Control/inventory system
- Material procurement plan

e) Quality assurance:

- Organisation structure

- Quality programme

- Quality control procedures and acceptance criteria

- Involvement of quality assurance organisation

f) Logistics:

- Capacity for manufacture of spares

- Operational support, test and diagnostic equipment

- Training aids, simulations, and other devices.

g) Contract administration

- Liaison between procuring agency and contractor

Detailed requirements are available in DOD directive 5000.38

The team for conducting the review may include the following:

- Contractor Programme/Project Manager (Chairman)

- Procuring agency Programme Manager (Co-chairman)

- Design engineers

- Quality assurance representative(s)

- Sub-contractor representative(s)

- Manufacturing representative(s)

- Procurement representative(s)

- Production planning representative(s)

Other people may be coopted as required.

CHAPTER FOUR

AUDITS

Configuration audits are used to verify that the configuration item (CI) comply with development requirements and conform to its Product configuration identification.

Two types of audits are carried out:[65]

- Functional configuration audit (FCA).

- Physical configuration audit (PCA).

The functional configuration audit confirms that the CI functions as required and is a prerequisite for design approval. The quality of the product is thus verified at the end of the Full-scale development phase.

The physical configuration audit confirms that the manufactured CI complies with its product design as identified in the Product baseline. The PCA is a prerequisite to production authorisation. The PCA is normally done in a pre-production run during the industrialisation phase.

Tailoring should be applied to select the requirements for each audit.

4.1 Functional configuration audit (FCA)

The functional configuration audit is required to validate that the development of a configuration item (CI) has been completed satisfactorily and that the CI has achieved the performance and functional requirements.[66]

The actual performance of the developed product is verified to establish compliance to the requirements in the development specification and the product specification.

This audit is normally conducted at the end of the full-scale development phase. Actual test data of the engineering development models are reviewed.

The following items should be included in the review:[67]

a) Testing information which will include:

- Test plans/procedures

- Complete list of successfully accomplished functional tests.

- Complete list of functional tests required by the specification but yet not performed. (To be performed as a system or subsystem tests)

- Detailed test results in the form of test reports.

b) A list of drawings of the CI to determine that the physical configuration of the CI for which the test data are verified was documented.

c) A checklist which identifies documentation, hardware and computer programs to be available and tasks to be accomplished at the audit.

d) Preliminary and critical design review minutes to establish that all findings have been incorporated and completed.

Properly validated test data (witnessed) accomplished by testing in compliance with approved test procedures should provide sufficient assurance that the CI performance as specified in the specification meets the quality assurance provisions which is also contained in the same specification.

Performance parameters which cannot be verified by the testing should be accepted when adequate analysis and simulations results are available.

After completion of the functional configuration audit, the contractor should publish and distribute copies of the FCA minutes.(68)

The team for conducting the review may include the following:

- Contractor Programme/Project Manager (chairman)
- Procuring Agency Programme Manager (co-chairman)
- Contractor System Engineer(s)
- Contractor Quality Assurance Representative(s)
- Sub-contractor Programme Manager(s)
- Contractor Test Manager.

Other people may be coopted as necessary.

For military projects, the FCA is conducted by the so-called technical committee. The committee consists of:

- Contractor Programme/Project Manager
- Procuring Agency Programme Manager
- Military Project officers
- Other procuring agency and contractor representatives as required.

Detailed requirements are available in MIL-STD-1521A Appendix E.

4.2 Physical configuration audits (PCA)

The physical configuration audit is a technical examination of a designated configuration item (CI) to verify that the CI "As built" conforms to the technical documentation which defines the CI.(69)

The PCA is normally conducted on the pre-production models to verify that the items were built according to the product specification. This audit normally takes place during the industrialisation phase. The PCA also determines that documented production acceptance testing requirements is adequate for accepting production items by the quality assurance activities.

A detailed audit of drawings, specifications and technical documentation is conducted. The audit should include a review of the build history in the form of quality control records of the configuration item.

The following items should be included in the review (as appropriate):(70)

a) Manufacturing instructions and drawings

- The manufacturing instructions are reviewed to establish that it accurately reflect all the design details contained in the drawings.

b) Records of baseline configurations, engineering release system and change control procedures.

- Records are compared with the engineering release system and change control procedures to establish that the configuration being produced does accurately reflect released engineering data.

c) Engineering release and change control system.

- The above system is audited to ascertain that it is adequate to properly control the processing and formal release of engineering changes.

d) Configuration of CI qualified and CI being audited.

- Differences should be recorded in the PCA minutes.

e) Acceptance test data, procedures and the CI product specification.

- The test data and procedures should be reviewed for compliance to the product specification.

f) Inspection and test data of sub-contractor equipment and items.

- Data should be reviewed for completeness and approval.

g) Back-up data which accompanies the CI for delivery.

- Back-up data should be reviewed for correct types and quantities.

After completion of the physical configuration audit, the contractor should publish and distribute copies of the PCA minutes.(71)

Detailed requirements are available in MIL-STD-1521A Appendix F.

The team for conducting the audit may include the following:

- Contractor Programme/Project Manager (chairman)

- Procuring agency Programme Manager (co-chairman)

- Contractor System Engineer(s)

- Contractor Design Engineer(s)

- Contractor Quality Assurance Representative(s)

- Sub-contractor Programme Manager(s)

- Contractor manufacturing representative(s)

- Contractor configuration management representative(s)

Other people may be coopted as required.

For military projects, the PCA is conducted by the technical committee as explained in 4.1.

CHAPTER FIVE

QUALIFICATION

To verify the traceability between the different baselines, of the selected phases, and compliance to the User Requirement Statement, use is made of the following processes:[72]

- Reviews
- Audits
- Qualifications

Reviews and Audits has been described in chapters three and four.

Qualification is a process in the Quality Assurance of the Acquisition process.[73]

Qualification testing verifies the design and manufacturing process.[74]

Qualification is a process which is applied to provide objective evidence that a system, item, material, process and software fully comply with all the requirements of the relevant specifications.[75]

The design of a product consists of different components parts and materials. Each component and material has physical and/or functional characteristics with specified tolerances. The objective of qualification of the design is to prove that the product can perform the required functions for any combination of the component and material characteristic measurements, within the specified limits of the component and material designs. To investigate all combinations, may not be possible due to practical and economic reasons. The acceptable risk involved that the product will not perform the required functions must thus be specified.

The qualification of the design must be expressed in terms of a reliability at a certain confidence level. The more items used to demonstrate compliance with functional requirements, increase the reliability of the qualification. Various statistical techniques exist to determine the risk associated with a qualification.

The quantified risk must thus be used with the word "Qualification".

The same principles apply to the qualification of the manufacturing processes. In this qualification process however, manufacturing process capabilities are evaluated and demonstrated. The processes are evaluated to determine if they can manufacture the product within specified design tolerances.

Three different qualification processes exist in the acquisition process:(76)

- System Qualification
- Design Qualification
- Process Qualification

To determine if the different specifications are traceable back to the User Requirement Statement, use is made of audits and design reviews. Reviews and Audits verify that the specifications were correctly derived from each other and is a Top-to-bottom approach.

The system specification is firstly derived from the User Requirement Statement, thereafter the item Development Specifications and then the Product Specifications.

To prove that the specifications were correctly derived from each other and comply to the User Requirement Statement, use is made of qualifications, which are a Bottom-to-top approach. Components are qualified, then the products and lastly the system.

Qualifications should be performed by competent personnel via effective physical and functional tests at specified environmental conditions.

5.1 Design qualification

To determine the correctness of the product and material specifications, materials/components/product sub-assemblies/products are built according to the product and material specifications and tested according to the test methods of the development specifications to determine compliance with the functional requirements of the development specifications. This test and evaluation process can be subjected to various iterations to resolve any problems in the product and material specifications.(77)

After these initial tests, a formal design qualification is done to prove that the materials/components/product sub-assemblies/products, which were build according to the relevant product and material specifications, comply to the requirements in the development specifications.

The results of the design qualification is qualified product and material specifications which describes the design.

The design qualification is a bottom-to-top process:[78]

- Materials which were manufactured according to qualified material specifications are used to manufacture components for the second level qualification.

- Components which were built according to qualified Product Specifications are used to manufacture product sub-assemblies for the third level qualification.

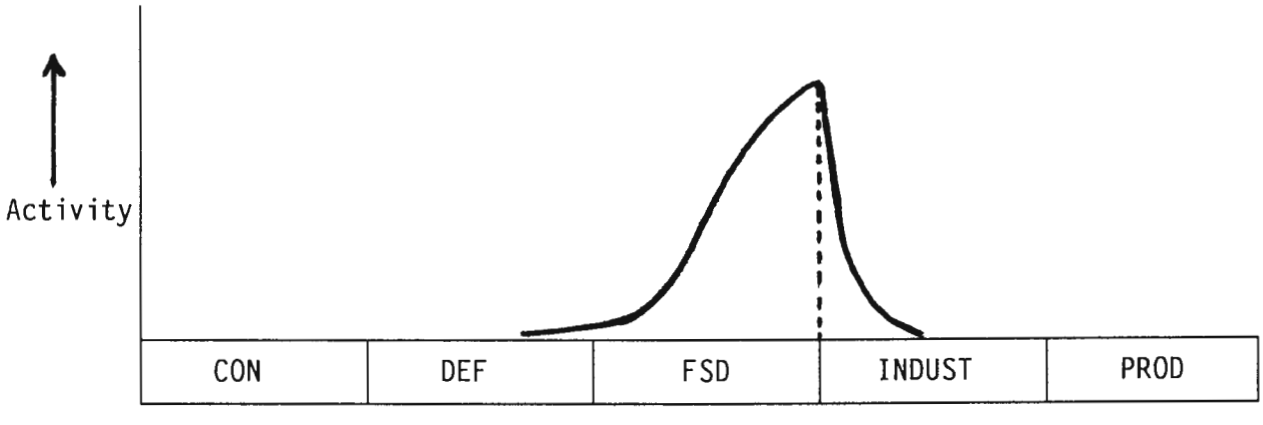
- Product sub-assemblies which were built according to qualified product specifications are used to manufacture products for the fourth level qualification.

- Products which were built according to qualified product specifications are used in the system for system qualification.

Design qualification is normally performed during the Full-scale development phase. The qualification activity during the acquisition programme is illustrated in figure 6. The final product is usually design qualified at the end of the full-scale development phase. Manufacturing process design may however require some product redesign. We therefore have some design qualification activity in the industrialisation phase.

FIGURE 6

Design Qualification Activity



5.2 System qualification

The system consists of different products which are manufactured according to qualified product specifications. These qualified products are integrated to form a system which are tested according to the test methods in the system specification to determine compliance with the requirement in the system specification. Various iterations of testing may be applied to resolve integration problems.

A formal system qualification is done to prove that the qualified products can be successfully integrated to comply to the requirements in the system specification.

The system qualification is done after completion of the design qualification of the different products. The system qualification activity may look the same as for the design qualification activity illustrated in figure 6.

5.3 Process qualification

Manufacturing Processes are developed during the industrialisation phase. These processes consist of plant, equipment, tooling, gauges, manufacturing instructions and operators.

The manufacturing processes are developed to manufacture the products according to design qualified product specifications.

After establishment and commissioning of the processes, it must be demonstrated that the processes are capable of manufacturing the product to the requirements of the product specification.

A formal process qualification is performed at the end of the industrialisation phase.

Pre-production models are built by making use of the manufacturing instructions, plant, equipment, tooling, gauging and trained operators and other relevant process documents. These pre-production models are tested and evaluated against the requirements of the product specifications. Test methods in the product specification are used to do the testing.(79)

A successful process qualification means that a qualified manufacturing process has been established.

This demonstration of process capability is documented in a process qualification report.

The process qualification is also a bottom-to-top process.

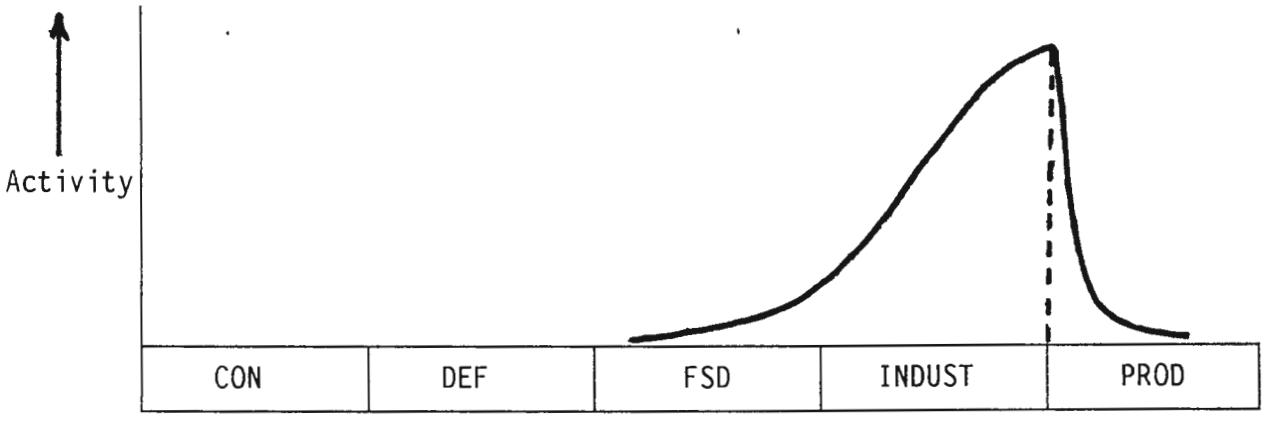
- Processes for the manufacture of materials and components are firstly qualified, then processes for sub-assemblies and lastly processes for the product.

Statistical techniques are employed to determine process capabilities. Use is made of X-Bar R Charts, P-Charts, NP-Chart, C-Charts etc. Process control is introduced to monitor process stability and centering.

Process capability studies should be performed in parallel with product design and the process qualification activity is thus started during the development phase. The peak of the process qualification activity is accomplished at the end of the industrialisation phase. Figure 7 illustrates the activity.

FIGURE 7

Process qualification activity



ACQUISITION PHASES

5.4 The scope of qualification

Qualification, i.e. design, system or process qualification, is a unique process in quality assurance and require carefull planning and execution. The following steps are required:

a) Development of qualification requirements

- A verification method is developed for every design characteristic in the drawing and specifications.

b) Development of qualification test.

- Design experiments to establish what and how to measure, statistical methods to be employed, accuracy required etc.

c) Development of the qualification test specification.

- Include all verification methods and qualification tests.

d) Compile test plan.

- Include responsibilities, time schedule, facilities etc.

e) Qualify test methods

f) Perform design, system or process qualification.

g) Compile qualification report

h) Approval of report after review and audit.

CHAPTER SIX

THE QUALITY ASSURANCE MODEL SUMMARISED

6.1 INTRODUCTION

Quality Assurance is necessary during the Acquisition process to ensure the integrity of the process and to verify that deliverable end products satisfy the requirements of the customer or user.

Without verification processes, unwanted products and systems are delivered to the user. This situation causes many problems, e.g. cost escalation and time delays due to re-development cycles and loss of contractor credibility. The responsible contractor looses potential future contracts and may even go bankrupt.

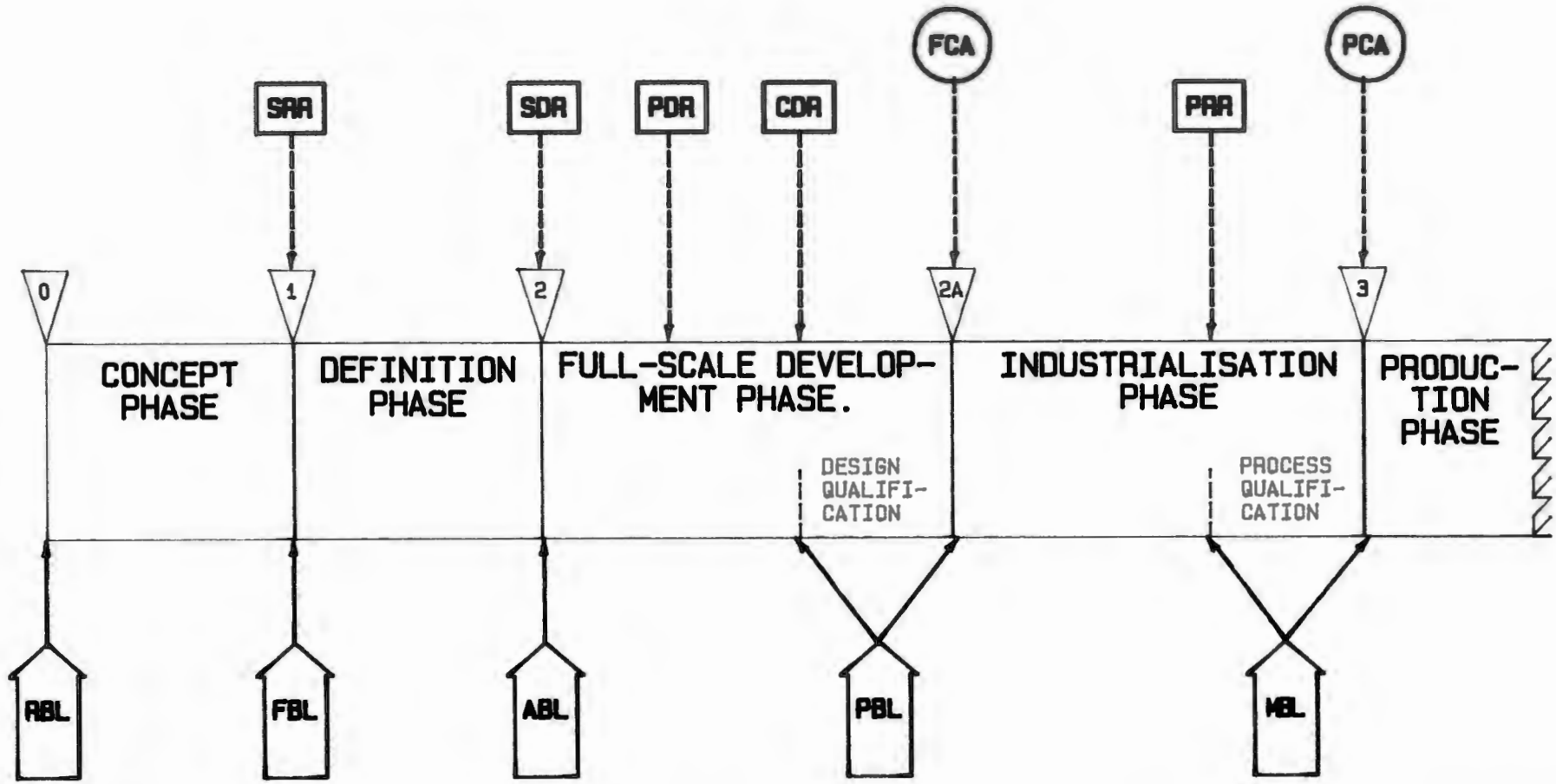
The previously described quality assurance processes, i.e. reviews, audits and qualifications, are all required during the Acquisition programme to verify that the end product or system will satisfy the original stated user requirements.

The purpose of this chapter is to introduce an integrated Quality Assurance model. The model will illustrate where each of the reviews, audits and qualifications fit into the acquisition programme and their relation to each other. These quality assurance processes all support each other to ensure that the end product or system will satisfy the original requirements.

6.2 The Model

Figure 8 illustrates the placing of each quality assurance process in the Acquisition programme. The processes are discussed and related in the sequence of occurrence during the Acquisition programme.

FIGURE 8
A TYPICAL QUALITY ASSURANCE MODEL



SRR = System Requirement Review
SDR = System Design Review
PDR = Preliminary Design Review
CDR = Critical Design Review
PRR = Production Readiness Review

FCA = Functional Configuration Audit
PCA = Physical Configuration Audit

RBL = Requirement Baseline
FBL = Functional Baseline
ABL = Allocated Baseline
PBL = Product Baseline
MBL = Manufacturing Baseline

The System Requirements Review (SRR) should be conducted at the end of the Concept phase to verify that the identified system, i.e. System Specification, contain all the ingredients to satisfy the input, i.e. User Requirement Statement, requirements. Without this verification it is possible that the wrong system will be developed and the consequences could be very costly. This review is very important because 65 % of the life cycle costs are committed by the end of the Concept phase. Refer to figure 4. The requirements of this System Requirement Review (SRR) and the items to be reviewed were discussed in chapter three.

The System Design Review (SDR) should be conducted at the end of the Definition phase to verify that defined configuration items or products, i.e. Development Specifications, and their interfaces, i.e. Interface Control Specifications, were derived from the system requirements as defined in the System Specification at the end of the previous phase. Without this verification it is possible that the wrong products will be developed or that the products will not interface with each other to be successfully integrated into a system. The implications could again be very costly as 85 % of the system's life cycle costs are committed by the end of the Definition phase. Refer to figure 4. The requirements of this review and items to be reviewed were discussed in chapter three.

The Preliminary Design Review (PDR) should be conducted during the Full-scale development phase when the preliminary product design is available. The review is necessary to ensure that the design concepts and approach are derived from the requirements in the Development Specifications and that interfaces between the different product designs are compatible. This review is necessary in the early design stages to avoid cost escalations and time delays when the detail design is found unacceptable at a very late stage. Design and development costs are normally high and this review ensures that detail design is not started until it is established that the concept design is acceptable.

The Critical Design Review (CDR) should be conducted during the Full-scale development phase when detail design has been accomplished. The detail designs as described in the Product Specifications are reviewed to verify that they satisfy the performance requirements in the Development Specifications. This review is necessary to establish that the design meets all requirements as described in chapter three. Without this verification it could be very costly and time consuming to demonstrate via testing, i.e. Qualifications, and redesign that the products meet the performances stated in the Development Specifications.

After verifying that the design is acceptable on paper, it is now necessary to demonstrate that the product will function and perform as stated in the Development Specifications. Objective evidence is required. Use is made of Design Qualifications to provide this evidence. Products are built according to the design drawings and tested according to the Development Specifications. The Design Qualification requirements were described in chapter five.

The results of the Design Qualification should now be reviewed to establish that performances in the development specification were achieved. The Functional Configuration Audit (FCA) is used to verify this. This audit is done at the end of the Full-scale development phase. The requirements of the audit were discussed in chapter four. The Product Specifications are sealed after this audit.

Without the qualification and audit it is not possible to state that the design will always meet the specified performances when manufactured in accordance with the Product Specification. Without these verification processes, the result may be re-design and re-development during the production phase. Costs could be very high due to scrap and rejected production items.

The qualified products are there after built and integrated into the system. System Qualification is required to verify that the qualified products when integrated meet the performance requirements of the System Specification. A Functional Configuration Audit is conducted to verify that the results of the System Qualification meet the performance requirements. Without a System Qualification it is possible that the delivered products will not satisfy user requirements when integrated, due to interface problems. This again could result in costly and time delayed redevelopment during Production.

A Production Readiness Review (PRR) should be conducted during the Industrialisation phase when the manufacturing processes has been defined and established. The production design is reviewed for completeness and producibility of the product design. This review should be conducted prior to the pre-production run and prior to the production phase. The requirements of this review were discussed in chapter three.

The manufacturing processes should be qualified to provide objective evidence that the processes can manufacture the product design according to the Product Specification. Without this verification it is possible that manufacturing process design cannot produce the product to its design and result in costly rejections of manufactured products.

A Physical Configuration Audit (PCA) should be conducted on the manufactured Pre-Production items to verify that the product meet its design criteria as specified in the Product Specification. Without this audit it is not possible to know whether the manufacturing process can produce the item to specification limits and tolerances. This audit goes hand-in-hand with the Process Qualification.

6.3 Implementation of the Quality Assurance Model

Tailoring should be applied to select the required reviews, audits and qualifications.

It is logical that for example, if no system is being developed then no system qualification will be required, but only a product design qualification.

The selection of the quality assurance processes go hand-in-hand with the complexity of projects, i.e. cost, schedule and technical risks involved.

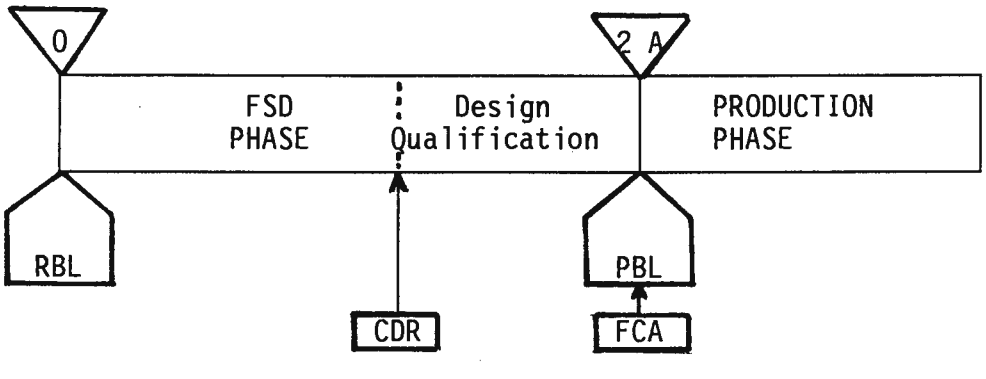
When risks are small due to low cost, short time schedules and known technologies the selection of quality assurance processes should be kept to a minimum. Reviews, audits and qualifications for non-complex systems or products may be less formal and requirements should be reduced to a minimum.

Example:

The following acquisition programme may be applicable for the development of a product with well-known technologies, small financial risk and a less important time schedule:

Figure 9

Example of an acquisition programme



The requirements of the reviews, audits and qualifications as described in chapters three, four and five should also be tailored to suit the need of each individual project. Requirements may be scrapped or changed as required.

Misapplication of the model can result in unneccessary development costs and delay delivery of the end Product.

The selected quality assurances processes should be documented in a Quality Assurance plan. This plan should be agreed by all parties concerned. The parties normally include:

- Procuring activity Programme Manager.

- Contractor Programme Manager.

- Contractor Quality Assurance Manager.

6.4 CONCLUSION

A Quality Assurance model has been established to verify that the outputs of the development process satisfy the input requirements of the user or client.

This model can be used as a guide for Quality Assurance planning on each project.

The structured stepped approach has been developed through experience in the United States Defence Industry and has a proven success record as explained in Chapter two.

No company can afford for Programme and Project Managers to learn by their mistakes, and this model is therefore useful as a guide for planning purposes.

Careful selection of the appropriate quality assurance processes and tailoring of the requirements for each selected review, audit and qualification must be performed to avoid misapplication of the model.

Properly planned and applied quality assurance actions will result in delivering the right product/system at the right cost and right time.

GLOSSARY

1. AVAILABILITY:

The probability that a system/item will operate satisfactorily at any point in time when a mission is started.

2. CONFIGURATION CONTROL:

The systematic evaluation, co-ordination and approval or disapproval and implementation of all approved changes in the configuration of a CI after formal establishment of its configuration identification.

3. CONFIGURATION IDENTIFICATION:

Each configuration item is described by a set of Technical documents. Eg. the Product is described by a Product Specification and design drawings.

4. CONFIGURATION ITEM:

An aggregation of hardware, software or any of its discrete portions which satisfies an end use function and is designated by the client for configuration management.

5. CONFIGURATION MANAGEMENT:

An discipline applying technical and administrative direction and surveillance to:

- Identify and document the functional and physical characteristics of a CI.

- Control changes to those characteristics.

- Record and report change processing and implementation status.

6. CONFIGURATION MANAGEMENT PLAN:

A plan which contains the responsibilities and procedures for implementing the requirements of Configuration Management.

7. COST-EFFECTIVENESS STUDIES:

A analysis to ensure that engineering decisions, resulting from the review of altenatives, are made only after considering their impact on system effectiveness and cost of acquisition and ownership.

8. ELECTROMAGNETIC COMPATIBILITY:

The evaluation of the system's design to withstand electromagnetic emission from other systems in the environment.

9. ENVIRONMENTAL CONDITIONS:

A climatic or mechanical environmental input to an item that affects its design, service life, or ability to function (Also referred to as an environmental stress).

10. ERGONOMICS:

The scientific study of the relationship between man and his working environment.

11. FAILURE MODE, EFFECT AND CRITICALITY ANALYSIS:

An analysis procedure which documents all probable failures in a system within specified ground rules, determines by failure mode analysis the effect of each failure on system operation, identifies single failure points and ranks each failure according to a severity classification of failure effect and probability of occurrence.

12. FUNCTIONAL ANALYSIS:

The identification and analysis of system functions in order to identify alternatives for meeting system performance and design requirements. The functions include the mission, test, production, deployment and support functions.

13. HUMAN FACTORS:

A body of scientific facts about human characteristics. The term covers all biomedical and psychososical considerations. It includes, but is not limited to, principles and applications in the areas of human engineering, personnel selection, training, life support, job performance aids and human performance evaluation.

14. LIFE CYCLE COSTS:

The total off all direct variable relevant costs for the whole System/Product over its whole life. It includes development, production, support, maintenance, operation, phasing-out etc.

15. LOGISTIC SUPPORT:

A composite of the elements necessary to assure the effective and economical support of a system or product at all levels of maintenance for its life cycle. The term includes the consideration of these elements during system/design engineering process, the procedures for analysing and documenting these considerations, and the process of planning for and acquiring these elements on a timely basis.

16. MAINTAINABILITY:

The probability that a System/Product will conform to or be retained in specified conditions within a given period of time when maintenance is performed in accordance with prescribed procedures and resources.

17. MASTER RECORD INDEX:

A controlled index of document numbers, titles and issue status of all configuration identification documentation which are required to adequately reflect the total identification of an item.

18. MISSION REQUIREMENT ANALYSIS:

The analysis of the impacts of system operational characteristics, mission objectives, threat, environmental factors, minimum functional requirements and technical performance. These impacts are examined continually for validity, consistency, desirability and attainability with respect to current technology, physical resources, human performance capabilities, life cycle costs, or other constraints.

19. OPERATIONAL TEST AND EVALUATION:

The test and evaluation conducted by a party other than the developer, to assess the systems operational effectiveness, operational suitability, logistic supportability, cost of ownership, and need for any modifications.

20. PROJECT MANAGEMENT:

The process of planning, organising, staffing, motivating, controlling and coordinating human and material resources for the execution of a facility to serve a specific function for the purpose of meeting predetermined objectives within the constraints of time, cost and quality.

21. QUALITY PROGRAMME PLAN:

The plan shall outline a programme for incorporating quality into design and conducting a comprehensive quality programme in accordance with the contract scope of work and specifications as listed in the contract. It shall portray how quality will be achieved to include schedule, technique, procedures, and responsibilities for each task.

22. RELIABILITY:

The probability that an item will perform satisfactorily for a specified period of time under a stated set of use conditions.

23. REQUIREMENTS ALLOCATION:

The allocation of each system function to a set of performance and design requirements.

24. STATEMENT OF WORK:

The basic framework for a clear statement of contract requirements. The statement of work specify basic responsibilities and minimum program requirements.

25. SYNTHESIS:

Sufficient preliminary design shall be accomplished to confirm and assure completeness of the performance and design requirements allocated for detail design. The performance, configuration and arrangement of a chosen system shall be portrayed in a suitable form such as diagrams, physical and mathematical models, computer simulations, layouts, drawings. These portrayals should illustrate interfaces, permit traceability between the elements of the system detail, and provide means for complete and comprehensive change control. These portrayals shall be the basic source of data for developing, updating and completing system and item specifications, interface control documents, technical and support manuals etc.

26. SYSTEM:

A composite of equipment and skills, and techniques capable of performing or supporting an operational role, or both. A complete system includes all equipment, related facilities, material, software, services and personnel required for its operation and support to the degree that it can be considered self-sufficient for its intended operational environment.

27. SYSTEM ENGINEERING MANAGEMENT PLAN:

A plan for the conduct and management of the fully integrated engineering effort. It includes the definition of system performance parameters and preferred system configuration to satisfy the requirement, the planning and control of technical programme tasks, integration of the engineering specialities, and the management of the design effort, speciality engineering, test engineering, logistic engineering and production engineering to meet cost, technical performance and schedule objectives.

28. SYSTEM ENGINEERING PROCESS:

A logical sequence of activities and decisions transforming an operational need into a description of system performance parameters and a preferred system configuration.

29. TECHNICAL PERFORMANCE MEASUREMENT PLAN:

The identification of high risk technical performance parameters for tracking during the development progamme. The plan shall include the specification requirement, time-phased profile of expected growth, method of obtaining value, and milestones, for each identified technical performance measurement parameter.

30. TEST AND EVALUATION MASTER PLAN:

A plan to define and integrate test objectives, critical issues, system characteristics, responsibilities, resources, and schedules for test and evaluation of the system.

31. TRADE-OFF STUDIES:

The evaluation to establish that feasible and adequate design concepts have been synthesized and to measure the relative advantages of each concept with regard to its performance, schedule, cost, and risk.

32. USER VALUE SYSTEM:

A prioritised list of requirements for the narrowing down of choices and milestone decisions. Affordability of acquisition, life cycle costs and timeous availability of skilled manpower and facilities should be primary components of the value system.

33. VALUE ENGINEERING

A cost reduction and control technique which is applied during the design stages of a System or Product and attacks the basic design of the product or system.

34. WORK BREAKDOWN STRUCTURE

A product-oriented family tree composed of hardware, services, and data, which results from development of a item, and which completely defines the Project/Programme. A Work Breakdown Structure displays and defines the product to be developed or produced and relates the elements of work to be accomplished to each other and to the end product.

REFERENCES

1. INTERNATIONAL STANDARD ISO 9000. Quality management and quality assurance standards - Guidelines for selection and use March 15, 1987 p.2.

2. UNITED STATES DEPARTMENT OF DEFENCE MILITARY HANDBOOK DOD-HDBK-248A Guide for application and Tailoring of requirements for Defence Material acquisitions October 15, 1979 p. 6.

3. KERZNER H. Project Management A systems approach to planning, scheduling and controlling New York Van Nostrand Reinheld Company Inc 1984 p. 24.

4. ARMAMENTS CORPORATION OF SOUTH AFRICA KB 1 000 Armscor Acquisition Policy September 24, 1988 p. 15.

5. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5 000.1 Major and Non-major Defense Acquisition Programs September 1, 1987 p. 3.

6. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 18.

7. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 20.

8. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 20.

9. ARMAMENTS CORPORATION OF SOUTH AFRICA System Engineering Management Module 1 System Acquisition Course notes volume 1.1 p. 60.

10. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969 p. 3.

11. UNITED STATES DEPARTMENT OF DEFENCE MILITARY HANDBOOK DOD-HDBK-248A Guide for application and Tailoring of requirements for Defence Material acquisitions October 15, 1979 p. 19.

12. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969 p. 4.

13. UNITED STATES DEPARTMENT OF DEFENCE MILITARY HANDBOOK DOD-HDBK-248A Guide for application and Tailoring of requirements for Defence Material acquisitions October 15, 1979 p. 20.

14. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969 p. 4.

15. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 36.

16. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969 p. 4.

17. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969 p. 4.

18. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 33.

19. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986 p. 6.

20. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986 p. 6.

21. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 60.

22. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986 p. 6.

23. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 18.

24. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988 p. 8.

25. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 18.

26. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988 p. 9.

27. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986 paragraph 3.1.3.1.

28. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986 p. 8.

29. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 19.

30. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988 p. 10.

31. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986 paragraph 3.1.3.2.

32. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986 p. 8.

33. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 19.

34. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988 p. 11.

35. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986 paragraph 3.1.3.3.

36. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986 paragraph 3.1.3.5.

37. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986 paragraph 3.1.3.4.

38. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 24.

39. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988 p. 12.

40. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 18 and 30.

41. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 18.

42. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 21.

43. ARMAMENTS CORPORATION OF SOUTH AFRICA KB1 000 Armscor Acquisition Policy September 24, 1988 p. 22.

44. ARMAMENTS CORPORATION OF SOUTH AFRICA KP009 Praktyk vir Tegniese Hersieningsrade en Magtigingskomitees September 7, 1988 p. 14.

45. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 69.

46. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 70.

47. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 1.

48. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 5.

49. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 3.

50. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 73.

51. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 73.

52. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 15.

53. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 15.

54. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 73.

55. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 16.

56. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 23.

57. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 74.

58. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 23.

59. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 40.

60. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 74.

61. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 41.

62. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 4.

63. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5000.38 Production Readiness Reviews January 24, 1979 p. 1.

64. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5000.38 (Encl 1) Production Readiness Guidelines January 24, 1979 p. 1.

65. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989 p. 79.

66. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 3.

67. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 55.

68. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 57.

69. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 3.

70. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 60.

71. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976 p. 65.

BIBLIOGRAPHY

1. ARMAMENTS CORPORATION OF SOUTH AFRICA KB 1 000 Armscor Acquisition Policy September 24, 1988.

2. ARMAMENTS CORPORATION OF SOUTH AFRICA KP001 Practice for Programme Management January 20, 1989.

3. ARMAMENTS CORPORATION OF SOUTH AFRICA KP009 Praktyk vir Tegniese Hersieningsrade en Magtigingskomitees September 7, 1988.

4. ARMAMENTS CORPORATION OF SOUTH AFRICA RSA-MIL-STD 0003 Acquisition Baseline Standards August 10, 1988.

5. ARMAMENTS CORPORATION OF SOUTH AFRICA System Engineering Management Module 1 System Acquisition Course notes volume 1.1.

6. INTERNATIONAL STANDARD ISO 9000. Quality management and quality assurance standards - Guidelines for selection and use March 15, 1987.

7. KERZNER H. Project Management A systems approach to planning, scheduling and controlling New York Van Nostrand Reinheld Company Inc 1984.

8. UNITED STATES DEPARTMENT OF DEFENCE MILITARY HANDBOOK DOD-HDBK-248A Guide for application and Tailoring of requirements for Defence Material acquisitions October 15, 1979.

9. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-280A Military standard definitions of item levels, item exchangeability, models, and related terms July 7, 1969.

10. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-483A Configuration Management Practices for Systems, equipment, munition and computer programs June 4, 1986.

11. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-490A Specification Practices June 4, 1986.

12. UNITED STATES DEPARTMENT OF DEFENCE MIL-STD-1521A Technical Reviews and Audits for Systems, Equipment, and computer Programs June 1, 1976.

13. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5 000.1 Major and Non-major Defense Acquisition Programs September 1, 1987.

14. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5000.38 Production Readiness Reviews January 24, 1979.

15. UNITED STATES DEPARTMENT OF DEFENCE DOD DIRECTIVE 5000.38 (Encl 1) Production Readiness Guidelines January 24, 1979.