Improvements of Aircraft Availability Within the Royal Netherlands Air Force

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ABSTRACT

Improvements in aircraft availability allow better assignment of aircrafts to specific missions. Aircraft Availability is important to reach the organisational goals like 'air power' and mission availability. The performance indicator Aircraft Availability gives insight of the contribution to the mission capability of the fleet.

Depending on the goal, there are different ways to calculate Aircraft Availability. In one definition of Availability the performance parameter depends on the Mean Time Between Failures and the Mean Time To Repair (corrective maintenance after a failure has occurred).

Improvements of Aircraft Availability are not always performed on the same level of the performance indicator itself, but on a more detailed level. In the above mentioned definition of Availability, a higher availability is reached by increasing the MTBF and/or decreasing the MTTR.

Within the RNLAF, Aircraft Availability is not monitored stand alone but in conjunction with other logistic indicators. All is embedded in the business policy "Integral Weapon System Management".

Defining the right indicators to control the availability is not easy; the indicators must be carefully tuned between business goals on the one hand and (maintenance and supply) processes on the other hand. Additionally, also norms, measurement band width and organisational requirements must be defined.

In this report an oversight is given of the used indicators of Aircraft Availability, and a start of the discussion of "What is a right indicator" is made.

1.0 INTRODUCTION

Aircraft Availability (AA) is a global performance indicator that is useful for management to control the fleet and the MOB. The RNLAF has incorporated a managerial control concept: Integral Weapon System Management (IWSM). The purpose of IWSM is to guarantee availability and exploitation of the system during the whole life cycle of the system. The intention is to seamlessly integrate supporting processes of the (weapon) system, by introducing standards and norms for logistics. The implementation of these logistics processes should be cost-efficient and minimising life cycle cost. This, however, may not influence airworthiness.

IWSM comprises the following function scopes:

- Product Management: determines the requirements of a weapon system, to during the whole life cycle meets the operational needs.
- Configuration management: identifies and controls configurations and changes in configurations.
- Integrated Logistics Support management: integrated logistics support of a weapon system, during the whole life cycle appropriate logistics support against controllable costs.
- Contract Management: set up of agreements with suppliers of products and services.
- Financial management: planning and realisation of cash flow.
- Quality management: organising and guaranteeing of quality, by a quality system according determined requirements of products, services, and processes.
- Administration: facilitates managerial information for IWSM.

The responsibility for each weapon system, such as F-16, Chinook, and Apache, is dedicated to the weapon system manager, who reports long term enhancements and periodically evaluation of the performance indicators. The weapon system manager is responsible for the managerial process of norms, requirements, and directives to control the underlying executing process.

In this IWSM management concept the emphasis is the realisation of employability of the weapon system. This employability or system effectiveness is divided into:

- Operational availability:
  - ➢ System reliability.
  - ➢ Maintainability.
- Mission reliability.
- Conformity of design.

These are the roots/fundamentals of the interest of the RNLAF in availability.

In the next section different kinds of availability will be explained, including their goal and definition. In section 3 some of the basic routines of working with indicators are described, supported with daily practices. Since aircraft availability is a too broad indicator to manage solutions of logistic processes, is section 4 looking for more appropriate indicators. The implementation of new performance indicators is pointed out in section 5. Finally in section 6 the conclusions are given.

2.0 AIRCRAFT AVAILABILITY

Availability is defined (according to NATO ARMP-7):

"the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided."

In the broadest sense, Aircraft Availability (AA) is defined as the portion of time the weapon system can fulfil the dedicated function. Availability is also dependent of reliability and maintainability of the system.

RNLAF divides AA into:

- Inherent.
- Operational.
- Scheduled.
- Unscheduled.

All four indicators are used by the RNLAF and have their own formula.

2.1 Inherent Availability

Inherent availability is a performance parameter that depends on the Mean Time Between Failures and the Mean Time To Repair (corrective maintenance after a failure has occurred). In mathematical terms, it can be defined as:

$$A_i = \frac{MTBF}{MTTR + MTBF}$$

Legend:
MTBF= Mean Time Between Failure
MTTR= Mean Time To Repair

Inherent Availability (A_i) is defined as the availability that does **not** take delay times into account like:

- Waiting for support capacity.
- Internal transport.
- Waiting time on spares.

Given the formula, it is obvious that a higher availability is reached by increasing the MTBF and/or decreasing the MTTR. The latter applies to corrective maintenance, whereas the first can be done by using high-reliability parts or by implementing preventive maintenance.

The A_i generates the highest possible upper limit of the availability of the system. The amount and the influence of any delays in the processes are depending on the way the logistic support has been implemented and is recognisable in operational availability (see Section 2.2).

A_i is a good indicator to evaluate the influence of the values of MTBF and MTTR of each of the (sub) components on the system as a whole.

2.2 Operational Availability

Operational Availability (A_o) in the contrary does include delay times, corrective and preventive maintenance. This is a more ‘realistic’ approach, since losses in processes are hard to prevent.

$$A_o = \frac{MTBMA}{MTBMA + MMT + MLDT}$$

Legend:
MTBMA= Mean Time Between Maintenance Actions
MMT= Mean Maintenance Time
MLDT= Mean Logistic Delay Time

The difference between MTTR (in A_i) and MMT is that MTTR only calculates an average of corrective maintenance activities and MMT involves both preventive and corrective maintenance actions.

The A_o is the indicator for employability and is dependent on the ratio of preventive and corrective maintenance and the accompanying delays, against the total active time of the system. This quantitative indicator gives insight in the areas (for example delivery delays or lead time of a maintenance example) in which the most successful improvements could be made.

Also A_o can be expressed as a ratio of the time in which the weapon system is available, over the total time that is to be taken into account.

2.3 Scheduled Availability

Next implementation of AA is scheduled availability, which calculates availability in a slightly different way. It is based on the time the aircraft is ready (fully or partially) for a mission and the time spent on scheduled maintenance. The formula for Scheduled Availability (A_s) is:

$$A_s = \frac{FMC + PMC}{FMC + PMC + NMC_{scheduled}}$$

Legend:
FMC= Full Mission Capable
PMC= Partly Mission Capable
NMC= Not Mission Capable due to scheduled maintenance

A_s is defined as the portion of time, in which a weapon system fulfils the needed function. In this definition only scheduled maintenance is 'planned'. Pre condition is that unscheduled maintenance is not calculated. The availability is calculated only to take into account preventive maintenance action.

2.4 Unscheduled Availability

Unscheduled Availability (A_u) is defined as the portion of time that a weapon system fulfils the required function, assuming there is no scheduled maintenance. The availability is calculated by corrective maintenance.

$$A_u = \frac{FMC + PMC}{FMC + PMC + NMC_{unscheduled}}$$

Legend:
FMC= Full Mission Capable
PMC= Partly Mission Capable
NMC= Not Mission Capable due to unscheduled maintenance

The RNLAF is interested in the availability of the F-16 minus time spent on scheduled and unscheduled maintenance. The goal is to reduce the unscheduled maintenance part. The causes of a high value of A_u is investigated.

2.5 Results

Monthly, management is reported on availability of the total fleet and per unit. The units are the MOBs of the Netherlands, the training, and out of area locations. The reports give insight in NMCM due to modification, preventive and corrective maintenance.

Table 1: Figures of Aircraft Availability.

Aircraft Availability		
	Norm (%)	Value (%)
Inherent	?	C
Operational	38	C
Scheduled	?	C
Unscheduled	?	C

Norms of inherent, scheduled and unscheduled availability are not defined yet. A_i is not measured, which doesn't mean there is no interest to deliver and control these figures, but at the moment there is no clearly defined method to measure the indicators.

These indicators, however, do not provide enough insight regarding system performance for management controlling the execution of the involved processes. Just indicating that the MTTR of component x is too long, is not enough to improve the MTBF. A detailed research is necessary, to explore the cause of the high MTTR. Is it because the delivery times of a new component or the old fashioned way to remove the component, or a sick maintainer?

To control the logistics and maintenance activities in more detail, the RNLAF has defined several performance indicators.

Table 2: Figures of other performance indicators.

System effectiveness			Maintenance			Logistics		
	Norm	Value		Norm	Value		Norm	Value
FH per tail	189		MTTR	?		Reliability of supply	80	
FH per range	?		MMH/FH	?				
Sorties	?		MMH	?				
Landings			…			…		

The table gives insight in which PIs are reported. The real figures are confidential. Also norms are hard to find due to the variance in circumstances in different periods. Also some logistic indicators are still under development.

In the next section more clarity about the difficulties with performance indicators are given.

3.0 PERFORMANCE INDICATORS

3.1 Introduction

A whole set of performance indicators is necessary to manage underlying processes. Starting at the highest level, with AA and further explored to e.g. number of landings. Currently, more attention is paid in defining the right indicator for a specific goal. The goal could be:

"Improve the availability of system x with 20%."

Since several delays are caused by the logistic support process, this process analysed and a start is made to define the right indicators to control the process.

Defining a performance indicator is not easy. A 'good' indicator is:

- Specific (What exactly is measured?). *Availability as in* $A_{o.}$
- Measurable Quantifiable (express in numbers). A_o *is hours (working days).*
- Acceptable (by owners and performers). $A_o + 5\%$.
- Realistic. *Increase of* A_o *in 2005 was 3%.*
- Timely. *To be achieved at 01/05/2007.*

A performance indicator is expressed in a number and is related to a norm. A norm is determined on forehand and there must be a certain competition to reach the norm. On forehand is needed because otherwise it is possible to manipulate the outcome. When a norm is 'too low', people do not get motivated by reaching the norm and they get disinterested. Striving towards a goal, gets the people motivated and willing to reach the goal.

Periodically the indicator is evaluated, and based on that information the process is adjusted or maybe new improvements are introduced. After a while, it is noticed that the norm is easy to reach. Then the norm is re-adjusted. The Plan-Do-Check-Act cycle is incorporated.

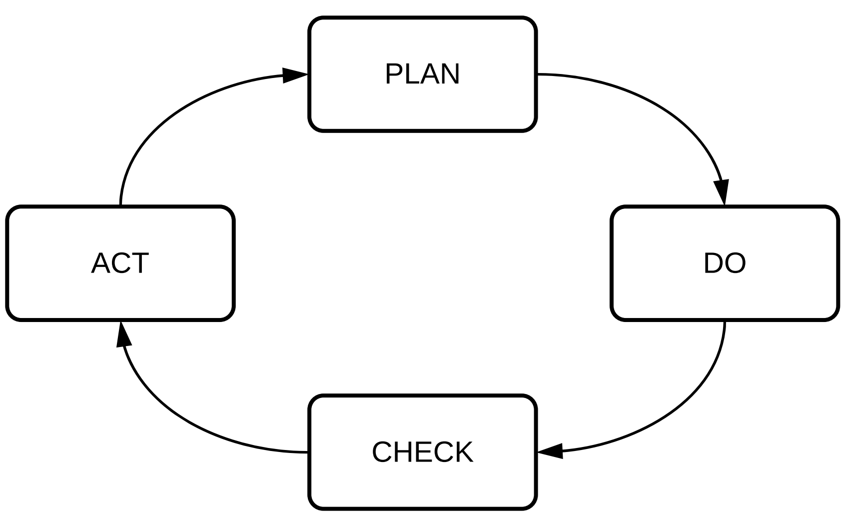

Figure 1: Deming PDCA cycle.

3.2 Goal

The A_o is divided into reliability of the system, and maintainability with the accompanying maintenance concept. These characteristics are geared to the logistic support organisation. The A_o of a system is subtracted from the operational demand (the total number of required flight hours). The goal of the RNLAF is to gain airpower. This is not possible without the necessary logistics support to system effectiveness.

The quantitative performance indicators of the RNLAF are set up to attain the goal of the indicator. Within the RNLAF, availability is addressed from a 'logistic' point of view and aims in particular for a lower MTTR. Repair processes may lead to a high MTTR due to inefficiencies. The supporting processes and available resources are decisive for the execution of the maintenance process.

Also, according to the IWSM concept, it is necessary to guarantee the airworthiness by improving processes against lowest possible life cycle cost (LLC). Nowadays, the LLC of the F-16 are approximately 23 billion Euros (see [1]). That gives a good reason to constantly improve the supporting processes and to keep control of the efficiency of the activities.

3.3 Level of Detail

The AA is calculated to the total fleet and this is a global indicator. Also AA is reported per MOB, which is a dedicated figure of the total availability of the F-16's of that MOB. The figures are influenced by some management/business priorities:

1) Out of area operations.
2) Training.
3) MOB flying.

Decisions sometimes are made to shift aircrafts from MOB flying in favour of an Out of Area operation. This influences the total availability of a unit.

The level of detail of the measured indicator is very important. For management at the highest level, like the head of the Department of Defence, it is sufficient, but at the shop floor, it is a very poor indicator of what is happening at the squadron.

Obviously, aircraft availability does not say a thing about the lead-times of a pre-flight inspection. The indicator must be tuned to the organisation level and the goal of the measurements.

Since the availability of the F-16 is decreased to 30 %, some extra countermeasures on logistic support were taken, like:

- Implementation of integral supply chain management.
- Training of personnel.
- Administration of war readiness kits.

These measurements are all aiming to remove the delays from the maintenance actions. The challenge in this area is to predict the expected demand of spare parts, and the date on which the parts are needed. Too often, modules or parts are sent to the supplier for repair and the expected return date is unknown.

3.4 Defining Norm

Mostly, the norm is defined as a result of expectations of the involved people. As soon as the first results are reported, a feeling whether it is good or bad, will come up.

Performing below the specified norm is (often) not immediately 'wrong'. There is a bandwidth that gives the playground in which the results can vary. The band width could be determined by the norm plus or minus 10%. Results within this band width are 'good', below the band width, actions of the action plan should be taken to improve the results.

Sometimes results are very fluctuating, and then it is hard to determine an appropriate norm (like "East" in Figure 2). The defined norm plus or minus 10% no longer persists. Taking the right actions is even harder, since the next period the indicator is performing well. The indicator is not chosen well, and a new indicator should be defined.

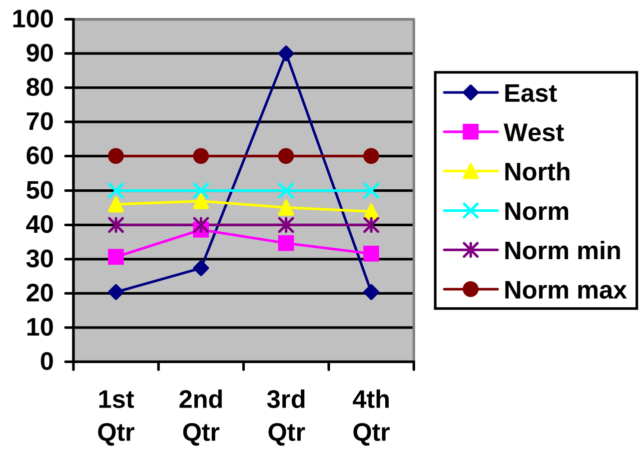

Figure 2: Results and norms.

3.4.1 Units of Indicators

Defining the unit for an indicator is also important. Questions like "Should the unit of this indicator be flight hours or 'normal' hours or can it be a day, 24 hours, or should it be 8 hours (a working day)" are central in this discussion. This should be determined on forehand.

In relevant cases, also the measuring instruments must be defined, e.g. a stopwatch or a wall clock. For maintenance actions of the F-16, the information system CAMS is in use. In CAMS, several maintenance parameters are registered. The information is used for the monthly reports. Indicators can be distracted from the CAMS database. The quality of the input is decisive of the calculation of the indicators. Everyone has to register the same information in the same database field, because otherwise comparison is impossible.

3.4.2 Plan of Action

There should be a plan behind this principle, which describes the actions that should be taken in case of results under or above the norm. In the plan, the possible causes of (for example) delays are described and which solutions for the causes are available. When the results are below the norm, the corresponding actions are taken.

Improvements are made when the target is adjusted in upwards direction. In that situation, a new norm with a new band with is defined.

4.0 NEW PERFORMANCE INDICATORS

Defining a ‘good’ indicator looks simple, but to define the sufficient set of indicators on each organisation level is not an easy job and requires dedicated precision. The challenge is to guarantee the relationship between strategic goals and the mutual influence of each indicator. For example, the goal is ‘airpower’. This is delivered by weapon systems. These weapon systems have, amongst other, a certain ‘system effectiveness’, which can be divided into:

- Operational availability.
- Mission reliability.
- Conformity of design.

The AA is too ‘global’ a parameter to control the process at MOB level. A specification (or breakdown structure), like above in more detail is necessary.

A well-defined indicator represents a thorough knowledge of the processes and its activities. Aircraft availability supposes knowledge of the aircraft, but also of the logistics processes. When the right set of indicators is chosen, the process is managed and improvements could be implemented following the plan (see Section 3.4.2).

4.1 Relevant Research

Research can be helpful in defining new performance indicators.

The National Aerospace Laboratory, NLR, is specialised in research on health and usage monitoring of aircraft. Airframe and engines are the main topics, for which parameters are identified that can help managing the supply and maintenance process. NLR is specialised in dedicated in depth research, where it for a ‘normal’ organisation not cost efficient is to hire a researcher.

Also, the RNLAF conducts several studies internally to investigate the main causes of a relatively low score on availability.

4.1.1 Engine Life Management Plan

The Engine Life Management Plan (ELMP) studies the Scheduled Depot Visits of the F-100 engine of the F-16, during the remaining life time of the F-16. The goal of this research was to make a model of a cost efficient method to phase out the F-16, with a sufficient fleet size of F-100 engines and without loss of airworthiness. Also, choices of upgrading, buying new modules, or repairing, are seen in the perspective of ageing.

The outcome of the study was a model which gives a prognosis of future maintenance actions. Several simulated time intervals to phase-out the engines were examined. The model calculates the most cost effective time interval for phasing out the engine.

Used parameters were start and end of the phase-out interval, usage (cycle rate), and fleet flight hours per year. The cycle rate is a good indicator for expected maintenance.

4.1.2 Module Matching

Maintenance of the engine is based on the consumption of engine cycles. After 2.000 or 4.000 cycles (depending on the module) an overhaul is planned. The goal is to select modules within one engine which match with respect to remaining life. This way scheduled maintenance will be in phase for the modules involved which will increase the engine availability.

In practice the feasibility of matching is limited. Swapping modules between MOBs in order to assemble engines with matching modules will (initially) give an (unacceptable) availability decrease. In addition, major module modifications may 'zero' the lifetime of a module inventory and thereby excluding matching opportunities.

4.1.3 Flight Regime Recognition

A 'regime' is considered as a combination of flight conditions, manoeuvres, and specific events such as rotor-start-stop-events. These regimes can be identified and classified according to their effect on fatigue damage. Regimes may also be combined with a distinctive parameter that indicates loads severity.

Figure 3: Chinook with load.

By flying a specific regime, the damage on the system can be predicted, and Life Cycle Management implemented. For example, hovering with a Chinook is less damaging to the airframe then transporting heavy loads. A sort of 'damage indicator' (Chinook Damage Indicator, CDI) can be defined, which gives an idea of the maintenance loads, and gives recommendation to the pilots.

During the study the tool "PROUD" (PROjected Usage Damage tool) was built. This is a simple and straightforward Chinook damage prediction tool in an Excel spreadsheet calculation, based on usage information. It is able to predict the relative severity of certain usage scenario's and OOA operations. The tool may support fleet managers, maintainers, operators, and planners in logistics decisions connected to future Chinook operations.

The proposed CDI is a useful parameter, but yet is not implemented in the 'normal' reporting cycle of the RNLAF.

4.1.4 Reliability Centred Maintenance

In this study, some 'new' maintenance performance indicators were defined. Goal of the research is to have insight in the reliability of engine maintenance and the (cost) drivers of maintenance. Indicators like Maintenance Manhours, shop visit rate, LRU rate are input to manage the logistic process on a regular basis.

This study will be finished by the end of this year, but is very promising regarding new appropriate and well-defined performance indicators.

4.1.5 Prognostic Health Monitoring

Recently, more attention is given towards 'on-condition' maintenance. The concept is summarised in the term Prognostic Health Monitoring (PHM). PHM is based on the consumption of the (remaining) lifetime of parts that is predicted by sensors. PHM has the ability to predict the future health status, and the ability to anticipate on problems and required maintenance actions. Thus, failing of parts is predicted and the accompanied maintenance actions are planned.

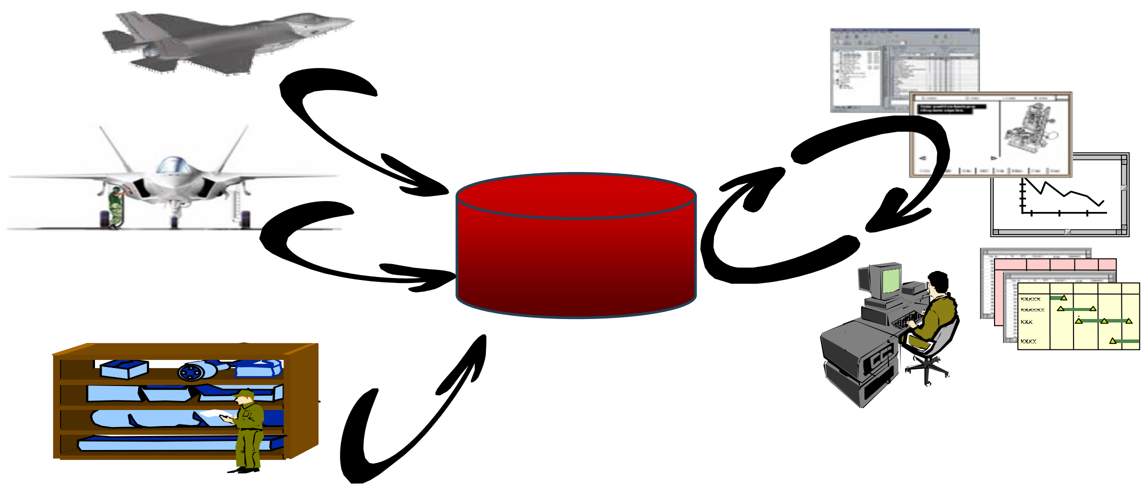

Figure 4: Tools of PHM.

This is achieved via the following pillars:

- *Diagnostics* – the process of determining the state of a component to perform its function(s).
- *Prognostics* – prediction of the remaining life or time span of proper operation of a component.
- *Health Management* – the capability to make appropriate decisions about maintenance actions based on diagnostics/prognostics information, available resources and operational demand.

PHM is one of the 'new' concepts of the JSF, but is also useful for legacy systems. By using PHM it is possible to extend the normal interval of inspections (e.g. from 150 to 200 FH). The concept uses many performance indicators to calculate the health of the system.

4.2 Control of Supply Chain Management

Supply Chain Management is the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption.

The whole supply chain management organisation should be ‘lean and mean’. Enhancing just a part of the chain leads to a partially optimised process, since the total chain stays as strong as the weakest link. Another advantage to of ‘chain management’ is that users are aware of their influence on the next step/activity of the chain.

A reorganisation within the RNLAF established article-, and SCM managers with an obvious role accompanied with responsibilities and competences. Besides that, internally are Service Level Agreements (SLA) installed to between partners in the supply chain: customers, suppliers, technical, and logistical departments.

4.3 Contracting Availability

Where possible, the RNLAF establishes Public Private Partnerships (PPP) to outsource dedicated activities. This influences the responsibility of a specific part of the process and that provide continuity in the process to reduce risks and that improve cohesion in maintenance activities.

Subcontracting the availability of spares, components, or systems based on operational availability is difficult, because the responsibility of delays can not assigned to the supplier, unless all maintenance is contracted by one supplier. On the other hand, subcontracting based on inherent availability also has its disadvantages since the supplier hardly can be appealed to delays in the process.

Contracting of availability is a discussion between measurements and responsibilities.

4.4 Supporting the Process

The RNLAF is preparing its organisation towards implementation of an Enterprise Resource Planning (ERP) tool. In this tool, not only personnel, planning and finances are incorporated, but also the above discussed indicators are included. The supply chain, with all its surrounding disciplines (Human Capital Management, Customer Relationship Management, Financial Management etc.) is controlled in more detail.

The ERP system is implemented at all armed forces, by a special project team Strategic & Process ERP Enabled Reengineering (SPEER). The team tunes the business processes to the ERP system. Diversity between armed forces is less possible, but maybe also reduces the benefits of a dedicated optimal measurements system.

5.0 IMPLEMENTATION ISSUES

The challenge is defining the right indicator, with the right norm, implemented by the right organisation.

5.1 Quality of Personnel

The most important production factor is human capital, but it is probably the one with mostly uncontrollable external circumstances. The RNLAF invest in their human capital with training and employees benefits. Unfortunately there are some (demographical) changes in the populations which are hard to restructure.

In the Netherlands, relatively a few students choose a career in technical jobs. Besides that, the RNLAF mainly offers short term contracts, so after three or four years, the technicians have to leave the building. The RNLAF had a tradition of life time employment, but that philosophy is left.

The Dutch government has made some drastic cut-backs in the defence budgets, and has defined a personnel maximum per function.

Also, RNLAF wants to play a role in Out of Area missions and these missions always comes first, which leaves people at the MOBs with high pressure of work.

The conclusion is that in this area, although this is very needed, improvements are not realistic.

5.2 Organisation

'The' organisation is responsible for implementing the right indicators. That is: not only defining it, but also evaluating and taking countermeasures. In an idealistic situation, the norms are being defined by another department then the department responsible for the measurements. This principle is called (in Dutch) "*controle technische functie scheiding*", which separates the executing process from the control processes.

5.3 Logistic Indicators

Several investigations lead to new insights on how weapon systems could be managed best. Measuring all parameters and indicators, is time consuming and inefficient, and, hence, a choice must be made. A new valuable indicator for logistics is the reliability of lead times. Goal is not only to plan maintenance better, but also to plan a Bill of Material with dedicated delivery times. The suppliers are 'forced' to give a planned delivery date and the technicians are 'forced' to plan their work.

5.4 Improvements of the Process

Controlling the supply chain from begin to end is not completely implemented yet. For example, when parts are sent to the repairing party, it is unknown when they will return.

The following (but not limited) improvements are possible:

- Smoothing of the procurement process to improve the availability of spare parts. This aims at having the right spare part, at the right time at the flight line.
- Reducing the time spent on corrective and preventive maintenance by having a closer look at the maintenance activities themselves.

6.0 CONCLUSION

AA looks a good indicator to have insight the availability of the fleet, but is not dedicated to the job of improving the availability. Therefore more dedicated and detailed indicators are necessary. Defining a good indicator is not easy. Experiences of other air forces are a welcome completion in this process.

7.0 REFERENCES

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[2] RAM, Reliability, Availability and Maintainability, Definities en gebruik. Versie 3.0. Ministerie van Defensie.