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Implementation of production availability programmes in engineering projects

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ABSTRACT: The aim of this paper is to present and discuss a methodology for implementing production availability programmes in engineering projects. The programmes are to ensure that the project goals will be met. The programme describes the production availability activities necessary to fulfil the objectives, how they will be carried out, by whom and when. The activities provide input to decisions regarding concept, design, manufacturing, construction, installation, operation and maintenance. The proposed methodology consists of three primary tasks and decisions. The three primary tasks are i) establish production availability requirements; ii) provide input to the design process and to operations; and iii) monitor production availability achievement and publish periodic report. Establishing the proposed methodology will help ensure that the project has a cohesive and cost-effective production availability programme, reflecting a production availability process and activities defined in view of the actual needs, available personnel resources, budget framework, interfaces, milestones, and access to data and general information.

1 INTRODUCTION AND BACKGROUND

The main objectives of a production availability programme (PAP) for a plant is to ensure that the right level of production availability is obtained for the plant. More specifically, the programme should initiate and see to that activities are run which (Aven, 1987; Rausand, 2002; Norsok, 2003):

- Compare different alternatives with respect to production availability.
- Identify relevant cost parameters.
- Predict production levels and availability for financial planning, cost/benefit evaluations and sales contract negotiations.
- Identify critical items requiring spare part attention and special requirement, and form input to spare part planning.
- Evaluate maintenance and operating strategies to see their effect on field performance.
- Identify system bottlenecks, vulnerabilities and components with unnecessary over-capacity.
- Evaluate the availability effects of system modifications, e.g. equipment redundancy and capacity modifications.

Such programmes are well known and have been applied by the Norwegian oil and gas industry for many years (Aven, 1987; Hokstad, 1988; Rausand, 1998; Signoret, 1998; Rausand, 2002; Enrico et al. 2006). A key document for these programmes is NORSOK Z-016 (2003), the standard established and used by the Norwegian oil and gas industry as a guideline for PAP. It covers the analysis of reliability and maintenance of components, systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum resources. However there is not much literature available regarding this subject for other industries. There are work covering reliability programmes for different industries, but not specifically addressing production and production availability. Their main focus is the process of ensuring a reliable product. We refer to Knowles *et al*. (1995), Klinger et al. (1992), Hagen (2006), Lentz (1995), Pecht et al. (2002), Guthrie et al. (1990) and Ke & Hwang (1997). We would also like to draw attention to the standards IEEE Std 933-1999, NASA-STD-8729.1 (1998), IEEE Std 1332-1998, ISO/CD 20815, and IAEA-TECDOC-1264 (2001).

The aim of this paper is to review the existing practice and present and discuss a methodology for implementing production availability programmes in engineering projects. The methodology identifies the primary tasks and decisions within the PAP and presents the activities required to perform the tasks

in the PAP and the tools that can be used in these tasks. The discussion addresses inter alia the following issues:

- What type of performance criteria and importance measures to be used.
- How to define and use performance criteria.
- How to convert the overall goals to more specific requirements.

This paper is organised as follows. First in Section 2 we give a brief overview of the principles and the main elements of a production availability programme. Section 3 presents and discusses the methodology. Section 4 concludes the paper.

2 AN OVERVIEW OF PRODUCTION AVAILABILITY PROGRAMME

2.1 *Production availability concepts*

Production regularity/availability is a term used to describe how a system is capable of meeting demand for deliveries or performance. Production availability, deliverability or other appropriate measures can be used to express regularity/availability (NORSOK Z-016). These are defined as follows (Aven 1987):

Consider a production system and let the rate of production at time t be denoted by $D(t)$ *and let* $D_0(t)$ denote the planned rate of production at time t. Then the throughput availability $A_1(t_1, t_2)$ is defined by the expected throughput relative to the expected demand, i.e.:

$$A_1(t_1,t_2) = \frac{\int_{t_1}^{t_2} E(D(t))dt}{\int_{t_1}^{t_2} D_0(t)dt} \quad (1)$$

An alternative measure is the demand availability $A_2(t_1, t_2)$, defined by

$$A_2(t_1,t_2) = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} P\big(D(t) \geq D_0(t)\big)dt \quad (2)$$

The demand availability expresses the expected proportion of time the throughput exceeds the demand. The on-stream availability, A_3, equals the expected proportion of time the throughput is greater than zero, i.e.

$$A_3(t_1,t_2) = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} P\big(D(t) > 0\big)dt \quad (3)$$

The availability at level c at time t, $A_c(t)$, is defined as the probability that the throughput is at least c at time t, i.e.,

$$A_c(t) = Pr\{D(t) \geq C\} \quad (4)$$

Relative to a level c, we can define an availability measure as the (expected) proportion of time the system state is at least c. If the production system is restored an "as good as new" condition after each failure, the average availability, which equals the mean proportion of time the system is functioning, can be written as

$$A_O = \frac{MTBM}{MTBM + MDT} \quad (5)$$

where the mean time between maintenance operations (MTBM) includes both unscheduled and preventive maintenance, and MDT is the mean maintenance down time and includes maintenance time, logistics delay time, and administrative delay time.

2.2 *Production availability programme (PAP)*

This section presents and discusses different elements of PAP based on the existing literature. A PAP is influenced by the policies of the organization, the product being developed, and by organizationally unique practices. These policies cause the PAP to vary from organisation to organization and from product to product. However, there are some common features, and these will be examined in the following. First we give a definition of a PAP (based on IAEA-TECDOC-1264 (2001):

A PAP is a formal management system, which assures the collection of important information about plant performance throughout each phases of its life, and directs the use of this information in the implementation of analytical and management processes which are specifically designed to meet two specific objectives:

- *Confirm that the plant is expected to meet, or continues to meet, each of the performance goals such as production availability, deliverability, and reliability.*
- *Guide the search and implementation process for cost effective improvements to the plant either to enhance production availability or reduce risk.*

The PAP will focus on the expenditure of resources available for performance improvement in areas, where the economic return is largest, or to optimize the design and operation of the plant.

A typical PAP will cover the following issues:

i) *Goals and performance criteria:* The PAP requires the definition and assignment of a broad set of high level plant goals and performance criteria which can be used for comparison with actual or predicted plant performance. The goals and criteria may be either deterministic or probabilistic. We will return to this issue in Section 3. For a recent and general reference on how to define appropriate goals and criteria, see Aven et al. (2006) and the references

therein. See also Hjorteland & Aven (2003) and Hjorteland et al. (2006).

ii) *Management and implementing procedures:* Management is a continuous activity throughout all phases of an engineering project. The following two management tasks need to be performed to ensure that the PAP becomes an effective tool:
   i) Develop, maintain, and implement a PAP plan, expressing what to do, how to do it, and who is to do it.
   ii) Establish and maintain a PAP review process: The PAP reviews should be conducted by experts who are not directly involved in the project team.

According to NORSOK Z-016 important tasks of management are to monitor the overall production availability level, manage reliability and maintainability of critical components and continuous identification of the need for production availability activities. A further objective of production availability management is to contribute with practical technical or operational recommendations. In order to fulfil these objectives, technical and operational means may be used during design or operation to change the production availability level. Production availability management must include surveillance of project activities and decisions which may have an undesired effect on production availability.

iii) *Analytical tools and investigative methods, Production availability analyses:* The question is how the system will perform in the future from a production availability point of view. Analysis of the system and modelling will increase the knowledge and hopefully reduce uncertainties. Production availability analyses provide a basis for decisions concerning choice of solutions and measures to achieve an optimum economy within the given constraints. The analyses must be performed at a point in time when sufficient details are available. However, results must be presented in time for input to the decision process (NORSOK Z-016, 2003). A PAP uses a set of investigative and analytical and/or simulation methods and approaches to calculate and maximize the reliability, availability and capacity of important subsystems or components. Examples of such methods and approaches are given in the coming section.

iv) *Information management:* The effectiveness of the PAP depends on the quality and accessibility of the information used to provide the feedback to the management systems about how well the system is performing and where to obtain improvements. Collecting production availability data is costly and this effort needs to be balanced against the intended uses and benefits. A typical data collection process may consist of collecting data from different sources into one database where type and format of data are pre-defined (ISO/DIS 14224). It is referred to Markeset and Kumar (2003) for some key factors influencing the management of reliability, availability and maintainability data and information systems.

3 IMPLEMENTATION OF PAP IN AN ENGINEERING PROJECT

This section presents the suggested methodology for implementing the PAP. The basis feature of the methodology is illustrated by the flowchart in Figure 1. The methodology is based on three main tasks:

- To establish PAP requirements;
- To provide input to the design processes and operations; and
- To Monitor PAP achievements and publish periodic report.

In the methodology, the starting point is the definition of project goals and performance criteria. There are two categories of performance measures: i) probabilities and ii) observable quantities. In our framework the overall goals and criteria are formulated based on ii). Observable quantities are quantities expressing states of the 'world', quantities of the physical reality or the nature, that are unknown at the time of the analysis but will, if the system being analyzed is actually implemented, take some value in the future, and possibly become known. Examples of observable quantities are production volumes, and the number of times production is below a certain number. Probabilistic quantities are not used to express such overall objectives. This is in line with the recommendation in Hjorteland and Aven, 2003 and Aven et al. (2006).

When the PAP requirements for the project functions are established (task 1), a primary design is developed to meet these PAP requirements (task 2). This design is then evaluated to see if the PAP requirements for the project function are being met and to identify critical functions and design elements (task 3). If the results of task 3 indicate that the PAP requirements for the project function will not be reached then the manager must decide whether the PAP requirements for the project function are attainable. If so, then the existing design should be revised to fulfil the PAP requirements, and the revised design should be re-evaluated to see if it meets the PAP requirements. This process needs to be repeated until the evaluation demonstrates that the requirements can be met.

If the PAP requirements are not attainable, they should be revised. If these requirements can not be revised in a satisfactory way, then the project goals should be either revised or cancelled.

Once the design is completed, it should be put in operation (task 2) by preparing the operation plan. This plan should be monitored and evaluated (task 3). If the

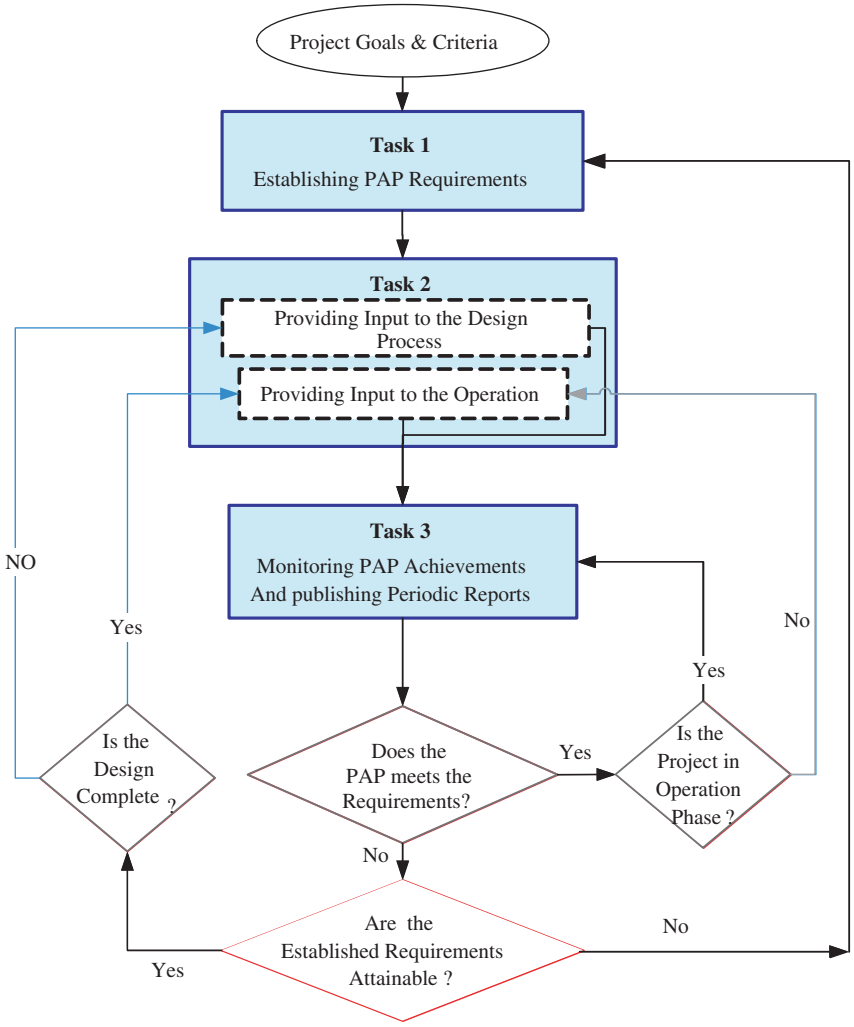

Figure 1. Production Availability Program (PAP) process.

results show that the requirements will not be met and the PAP requirements will be attainable, the operation plan should be revised and re-evaluated again. This process needs to be repeated to find a suitable operation plan meeting the PAP requirements.

Accomplishing the above-mentioned PAP tasks require the following activities:

- Management;
- Modelling and analysis;
- Testing;
- Data collection and analysis; and
- System design and logistics.

Different tools are available for the PAP programme. Table 1 lists several PAP tools for each plan activity.

In the following we briefly discuss each of the three primary PAP tasks for an engineering project.

3.1 *Establishing PAP requirements*

The specification of production availability requirements can be considered for system design, engineering and purchase of equipment as well as operation in defined life cycle periods. The task of transforming overall project goals to specific requirements is difficult. When it comes to cost, effect on safety, and other concerns, it is almost impossible to know what the proper requirements should be without knowing what such requirements imply and mean. For further discussion we refer to Aven et al. (2006).

Table 1. Production availability activities and tools.

Activities	Tools
Management	Production Availability Programme Plan Production Availability Review Process
Modelling and Analysis	Reliability Block Diagram Analysis Failure Mode, Effects, and Criticality Analysis Fault-Tree Analysis Markov Analysis Event-Tree Analysis Cause-Consequence Analysis Maintenance-Engineering Analysis Life-Cycle Cost Analysis Sneak-Circuit Analysis Tolerance Analysis Part-Count Analysis Growth Analysis Monte Carlo Simulation Petri net Modelling Bayesian Modeling
Testing	Production availability Test Plan Test, Analyze, and Fix Process (Growth Testing) Environmental Stress Screening Reliability Qualification Testing Reliability Acceptance Testing
Data Collection and Analysis	Generic Data Development Failure Reporting, Analysis, and Corrective Action System
System Design and Logistics	Redundancy and Diversity Modularity and Diagnostics Part Control Programme Production Availability Procurement Specifications Preventive Maintenance Programme Corrective Maintenance Programme Spare-Part Programme

Establishing PAP requirements can be subdivided into two subtasks:

Identifying the project functions: The objective is to identify the various functions which performances or accomplishments are essential to achieving the goals of the project. It is the responsibility of the project manager and designers to ensure that the functions of the project are defined. In general, the PAP must focus on the functions or specific tasks and missions of design elements instead of the design elements themselves. This is because a particular design element can perform several functions and the consequences of the failure of one function are likely to be quite different from the consequences of the failure of another function.

Translating the project goals into production availability requirements for each project function: The aim of this task is to translate each of the project goals into requirements for each project function. The PAP requirements can be qualitative, quantitative, or both, depending on the project. The requirements may be expressed based on performance measures such as production availability, throughput capacity, system availability, time to failure, time to repair, spare parts mobilisation times, and etc. They can also be expressed in terms of the design criteria for the product, system configurations, inherent safety (acceptable consequence of a failure), availability activities to be performed, etc (NORSOK-Z016). Let us look at an example.

Consider an offshore installation producing oil and gas. Table 2 depicts the high-level goals and high-level sub-gaols for such an installation in the operation phase (Aven et al. 2006).

The starting point for translating the goals to the requirements is the identification of the various functions that are important for achieving the goals of the project. In this case, examples of such functions are:

- The gas, separated by the separation unit from the water and oil coming from the well, is first compressed by two turbo-compressors (TCs), then dehydrated through a triethylene glycol (TEG) unit and finally exported.

Table 2. Goals for an offshore installation.

Situation	High-level goals	High-level sub-goals	Measures
Operation of the installation	High profit No fatalities No significant release of oil No environmental damage No injuries with permanent disability Few injuries Meeting all laws and regulations	"Optimal" regularity (production levels and deliverabilities) No major leaks No ignition if leaks occur	Operation and maintenance management, safety management

- The oil coming from the production well is separated by the separation unit and after treatment exported through a pumping unit.
- The water coming from the well is separated by the separation unit and after treatment reinjected.

Based on these functions, some sub-level requirements could be defined:

- The separation unit and the TEG unit shall have a minimum probability at a demand (e.g. 4.4×10^6 Sm^3/d) equal to x.
- Each TC shall have a process capacity of 2.2×10^6 Sm^3/d with minimum probability of y.
- The pump unit shall have a minimum probability at demand equal to z.

Instead of a sharp level of requirements, ranges of probability may be used. For the x%, y%, and z% requirements to be meaningful, it must not be seen as a sharp line; we should always look for alternatives and then evaluate their performances and depending on the situation we may accept different levels of requirements. This principle can be applied for all functions and by this the high-level requirements (which could be formulated as "confidence in meeting the goals") are ensured. The primary focus is on establishing production availability requirements for each function which is important for achieving the project goals and then on translating these requirements to the systems designed to accomplish these functions.

3.2 *Provide input to the design process and to operations*

Once the production availability requirements are established (task l), the PAP programme should address them by providing input to the design process and operation (task 2). For the design process, this means using a variety of PAP-related design techniques or tools such as Redundancy and Diversity, Modularity and Diagnostics, and Reliability vs. Maintainability Trade-off Studies, to help establishing a design that meets the qualitative and quantitative PAP requirements. In the design process, different alternatives should be generated and their performance evaluated, the aim being to balance the pros and cons of the alternatives (Aven et al. 2006, Aven & Vinnem 2005).

For the operation process, this means having programmes such as a Spare-Part Programme and a Preventive Maintenance Programme in place in order to ensure that the required equipment reliability, maintainability, and capacity are achieved. In the operation phase, observations of performance of the installation should be made to evaluate the need for measures, modifications, and improvements.

3.3 *Monitor PAP achievement and publish periodic reports*

Once a design has been developed to meet production availability and other project requirements (task 2), the PAP status should be monitored in order to predict possible production availability achievement in both design and operation phases and periodic reports should be prepared including relevant PAP information (such as goals and performance criteria, the status, data collection, data analysis). This information could used to:

- Decide whether PAP requirements are being met or not.
- Identify critical functions and design elements that need more attentions.
- Make specific recommendations for design and operation improvements.
- Identify critical failure modes, and
- Predict the production availability level.

A function or a design element can be identified as critical based on its *"importance"*. There are several measures of *"importance"* and many are commonly used in the reliability, maintainability and availability process. The appropriate measures depend on the specific decisions that need to be made. Identifying the critical functions and associated design elements at a particular level of design detail provides important feedback for establishing the production

availability requirements (task 1). The established PAP requirements provide input to the design efforts and the operating strategy (task 2).Two important factors are:

- the availability of relevant data, and
- the accuracy required for decision making.

The uncertainty in the predictions made during the initial design stages would be relatively high because of the lack of design detail. As the design becomes more detailed, relevant generic data can be used to obtain more accurate predictions. Finally, as sufficient testing and operating data become available, the uncertainties in the predictions will be further reduced. The effectiveness of the PAP depends very much upon the quality, accessibility and fidelity of the information used to provide the feedback to the management systems about how well it is performing, and where to make improvements. The experience from the operational phase of the project shall be transferred to parties involved in the design phase in order to stimulate improvements in design of new equipment and installations. This includes a review of assumptions made for the predictions in the design phase in comparison to actual conditions experienced during operation, including operational principles and maintenance logistics.

4 CONCLUSIONS

In this paper, we have studied different aspects of a production availability programme. A methodology for implementation of production availability programmes is proposed and discussed. The methodology consists of three tasks and decision criteria. Based on PAP goals, a set of relevant performance measure must be defined. For transforming overall project goals to specific requirements, we argue that the focus should be on establishing production availability requirements for each project function which is important for achieving the project goals and then on translating these requirements to the systems designed to accomplish these functions. The requirements should however not be seen as sharp lines; we should always look for alternatives and then evaluate their performances and depending on the situation we may accept different levels of requirements.

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