Dependability and Maintenance: their Interrelation and Importance in Industrial Operations Sustainability

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Abstract: - In a global world, the survival and sustainability of industrial companies depends on several factors: production continuity; quantity assurance; quality assurance; competitive prices for products; on time production; flexibility; operational safety and environmental safety. To achieve these goals, sustainable industrial operations must rely on dependable systems and equipments. Dependability is defined as “the collective term describing the availability performance of any simple to complex product” [1]. This definition can be extended for industrial operations, to their reliability and maintainability design characteristics. As there are no perfect systems and equipments designs, component degradation and failures will always occur during their life cycle. So to keep their dependability level during the life cycle good maintenance support is essential. In this paper we will discuss the importance of maintenance to achieve the required dependability and sustainability for industrial production processes and how that can be achieved.

Keywords:- Dependability; Maintenance; Sustainability.

1 Introduction
One of the main characteristics of the industrialised societies today it is their dependence on more and more technologies to deliver goods and services. In all business areas (services or industry) there is the vital need to use more sophisticated equipments that tend to apply new technologies, in order to improve the quality of produced services and/or products, with operational safety and environmental sustainability. This is the only way to guaranty the survival of companies in a globalised world and in a very competitive business environment. And this business environment is oriented towards profitability more then ever and it is focused on customer value and time-to-market as the most important drivers. And it is commonly accepted that customers value more and more the environmental safety and sustainability of technological products.

Also, management decisions must be taken very rapidly to respond to a business environment that is always changing in a fast way, what means that for the competitiveness of businesses they must be able to act very quickly to changes.

So, one can say that the survival of any business depends on its capacity of competing in a very efficient way in every moment and in a situation where the markets have very fast and sometimes unpredictable changes. For that to be possible, it is necessary to make use of more and more complicated technologies, which must be available and safe when needed. That means that every failure in the productive systems that affects their availability, energy efficiency and operational safety for people and the environment must be avoided, as it can affect companies’ survival, in the worst scenario.

In the case of industries they are expected to produce products to the market with good quality of service, which means it is expected that industrial operations are able to assure:

- Production continuity;
- Quantity;
- Quality continuity;
- Competitive “production” costs;
- On time production;
- Flexibility;
- Operational safety;
- Environmental safety and sustainability.

All this must be achieved in a situation where:

- Production systems are more and more sophisticated and, many times, are production networks;
- Equipments technological life tends to be shorter;
- More stresses on equipments, to improve profitability;
- Fewer investments in equipments.

This last point implies that industrial systems are designed with a smaller number of components development tests, they make more use of COTS (Commercial Off The Shelf) components and

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assemblies, with a reduction of operational tests and more systems and component design modelling.

In such an industrial environment, it is needed to make use of dependable equipments, which can guaranty a good quality of service. It must be noticed that sophisticated ERP (Enterprise Resource Planning) tools can only be useful if the production systems are dependable, otherwise they will fail to achieve their goals.

In this paper we will discuss the factors that influence industrial systems dependability and sustainability and how maintenance is a key factor to have dependable industrial systems.

2 Dependability of industrial systems

The definition of dependability is “the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance. Dependability is only used for general descriptions and is used in non-quantitative terms” [1].

Performance can be defined as the capability of the system to deliver the required functions, in an environmental safe and energy efficient way. Availability performance can be defined as the capability of the system to deliver the required functions under given conditions at a certain moment or time interval, if the required external resources are provided. Reliability performance is the ability of an item to perform a required function under given conditions for a given time interval. Maintainability performance is the capacity of an item to be retained in, or restored to a state in which it can perform a required function, in an expected operational environment, when maintenance is performed under stated conditions and using stated methodologies, procedures and resources. Maintenance support performance is the ability of a maintenance organization, in an expected operational environment, to provide when needed the resources required to maintain an item in a state it can deliver its function.

Also and in a very broad way, one can say that the main Dependability Attributes are:

- **Reliability** - Measure of continuous correct service delivery (dependability with respect to continuity of service);
- **Availability** - Measure of correct service delivery with respect to the alternation of correct and incorrect service (dependability with respect to readiness for usage);
- **Safety** - Measure of continuous delivery of either correct service or incorrect service after benign failure (dependability with respect to the non-occurrence of catastrophic failures);
- **Security** - Dependability with respect to the prevention of unauthorized access and/or handling of information;
- **Robustness** - The degree to which a system or component can function correctly in the presence of invalid inputs or stressful environment conditions;
- **Sustainability** - It is the ability to maintain a certain industrial process, using only the indispensable resources (materials and energy).

All these attributes must stand during all the systems life cycle.

It must be noticed that high availability and environmental and operational safety is often associated with fault-tolerant systems. The term *fault-tolerant* means a system can operate in the presence of hardware component failures. A single component failure in a fault-tolerant system will not cause a system interruption because there is a redundant component that will take over the task transparently.
If an industrial production system is considered as a network of different subsystems, the dependable system performance is influenced by two major technological factors [2]:

- **Nodal dependability** – there must be reliable network integration between the different subsystems to ensure adequate performance capacity;
- **Functional dependability** – there must be an effective management of flows between the different subsystems.

The business drivers of today’s industrial activities imply that industrial production systems must be dependable. These business drivers can be seen on Figure 2.

These business drivers are a function of the technical dependability of the whole production system, which is to say that they are dependent on the reliability, maintainability and maintenance support. Reliability and maintainability must be considered in the initial design stages of the system, as the major maintenance drivers depend on them.

### 3 Maintenance support approach

To operate an industrial production system efficiently in the long term at an optimum life cycle cost it is necessary to plan maintenance support activities, and bring to service the necessary resources. These activities shall start at the concept and development phase and shall go on throughout all life cycle phases. As it was seen earlier in this paper, the maintenance approach depends on how reliable and maintainable is the system to perform the required functions in a given operational environment.

At the development phase the “client” of the system should describe the requirements of it such as:

- The operating environment;
- The planned life;
- The “product quality” expected;
- The cost limits for maintenance;
- The types of maintenance he will be able to provide;
- The resources available;
- The relevant legal requirements.

These requirements will have to be considered during the design stage of the system and the maintenance concept and programme will have to be adapted to these requirements. It is well accepted at this stage that the reliability of the system and its components is defined and that components that are least reliable should be most maintainable.

So, the amount and type of maintenance and maintenance support depends on the user needs, the nature of equipments, specified availability and other factors, as we have seen. Also, as these factors change, especially during the operation and maintenance phase, maintenance may need to be adjusted.

After the definition of the operational requirements in a given operational environment, it is needed to develop what can be called the maintenance concept, which provides a plan for the system maintenance in terms of:

- Criteria for choosing levels of maintenance;
- Policies and requirements for maintenance support;
- Criteria for monitoring and test equipment.

This maintenance concept also depends on the maintenance policy, which must be defined in order to have the general approach for the maintenance provision and support based on the objectives and policies of the different system’s stakeholders.

So, the maintenance concept is the specific maintenance analysis developed for items using different levels of maintenance based on the indenture levels.

The main difficulties to develop the maintenance concept and planning are to define what a “failure” is (i.e., what is the degree of deterioration that can be accepted) and then develop the preventive and corrective tasks.

![Diagram of Maintenance Policy and Concept](image)

**Figure 3 - Maintenance policy and maintenance concept (adapted from [1])**

A dependable system is one that is able to avoid failures that are more frequent or more severe than it is acceptable to the users. So, it is necessary to identify which failures must be prevented, because they are not acceptable to happen and which are the preventive and/or corrective tasks that must be carried on. This can be done using different analysis and prediction techniques.
Among them:
- Fault modes, effects (and criticality) analysis, FME(C)A;
- Reliability centred maintenance (RCM);
- Fault tree analysis (FTA).

The FME(C)A analysis are ideally carried out during the reliability design process and systematically indentifies the likely modes of faults (failures), the possible effects of each fault, and the criticality of each effect on the system performance and safety.

As it is well known, RCM consists of a systematic approach to analyze the system reliability and safety data in order to determine the feasibility and the need of preventive maintenance tasks understand maintenance difficulties for design review and establish the most effective preventive maintenance programme.

FTA is a top down structured approach that identifies the possible causes that can lead to a fault of an item/component/equipment/system. It is particularly suited for the analysis of complex systems.

For the identified maintenance tasks an analysis should be performed in order to isolate it and to understand how it should be treated. It is necessary to record the following information:
- Maintenance requirements (eg: remove, adjust,…);
- Maintenance frequency expected;
- Human resources needed;
- Spare parts, tools and consumable materials;
- Location;
- Time estimate for the completion of the task.

A maintenance worksheet should be developed for the most important maintenance tasks.

Based on the definition of the maintenance tasks during the life cycle of the system the resources need to allow the achievement of the operational requirements must be identified and acquired.

It must be noticed that the maintenance tasks can change during the equipment life cycle. This occurs along the equipment life both with time and/or also influenced by changes in the operational environment. So, the maintenance tasks must be adjusted to the new reality of the system. Also, the information gathered by condition monitoring and by the feed-back from the field is essential to re-shape the maintenance tasks and can be very useful to re-design the system/equipment, in case of need, or for the design of new equipments.

4 Dependability analysis and assessment

As we have seen, dependability is linked to “product” (industrial system) quality and to its value. The “customer” confidence must be gained through appropriate design, manufacturing and delivering processes. During the life time, maintenance support must maintain this confidence by performance demonstration.

Dependability is commonly measured in terms of availability performance. As availability performance is a direct function of reliability and maintainability, their performances must be measured. Also, the maintainability performance depends on the quality of the maintenance support.

In general, availability is defined as a percentage measure of the degree to which machinery and equipment is in an operable and committable state at the point in time when it is needed [3].

Inherent availability, \( A_i \), reflects the fraction of time that a system is available if no delays due to maintenance, supply, operation planning, etc. (delays not design related) are encountered:

\[
A_i = \frac{MTBF}{MTBF + MTTR} \times 100\%
\]

MTBF is the Mean Time Between Failures and MTTR is the Mean Time To Repair.

If the system never fails, the MTBF is infinite and \( A_i \) is 100%. Again, if MTTR is 0, then \( A_i \) is 100%. As it is evident, if reliability decreases, better maintainability is needed to achieve the same availability and vice-versa. So trades can be made between the two to have a given inherent availability.

Achieved availability is the probability that a system will be in a state of functioning when used as specified taking into account the scheduled and unscheduled maintenance:

\[
A_a = \frac{MTBM}{MTBM + AMT} \times 100\%
\]

MTBM is the Mean Time Between Maintenance (Actions) and AMT is the Active Maintenance Time. Operational availability is the probability that the system will be in a state of functioning when used as specified taking into account all non-design factors, including maintenance:

\[
A_o = \frac{MTBM}{MTBM + MDT} \times 100\%
\]

MDT is the Mean Down Time and includes MTTR and all other time involved with downtime.

Operational availability is required to isolate the effectiveness and efficiency of maintenance operations. It is the performance experienced as the plant operates at a given production level. The difference between achievable and operational availability is the inclusion of maintenance support. Achieved availability assumes that resources are 100 percent available and no administrative delays occur in their application.
So, not only systems must be designed to be easy to maintain in its operational environment, but all the maintenance logistic support must be in place to be able to achieve the values of maintainability at the necessary level. That means to have an operational MDT that can give acceptable values for the system’s availability.

The EFNMS (2001) has defined the KPI (Key Performance Indicators) that help the maintenance manager to control the different components of the MDT and to understand why the maintainability levels are or not in accordance with what is required. A resume of this KPI’s is shown in Figure 4.

5 Conclusions
Dependability is essential for the guaranty of quality of service of companies. This quality of service is essential to their competitiveness and sustainability in a more and more technological and globalized world.

Dependability is usually measured by the system’s operational availability. Maintainability is one of the main factors in achieving a high level of operational availability, which increases the “customers” satisfaction.

Dependable industrial systems need fewer resources (energy, raw materials, among others) to achieve their technological goals, so they can be considered more sustainable systems when their performance is compared with less dependable ones. An industrial system that is not dependable usually is not energy efficient and the operational overall costs are not acceptable.

Also, to have a high level of operational availability the maintenance support is essential to have the expected values for the MDT – Mean Down Time. Maintenance is a complex part of the life cycle of a dependable and sustainable system. It must be considered since the concept and the design phases of the system and must receive the necessary logistic support during all the phases of the system life cycle.

References: