

System Approach for Improving the Dependability of Production Systems, State of the Art

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Abstract

During all the historical processes which the world knew in the industrial field, from the first manufactures until today, while passing by course of the industrial revolution in XIXth century, the development of the mode of management of the company made always the concern for managers, business leaders and industrial researchers. The way to see, consider, understand, analyze and lead an organization must depend on the environmental constraints applied, because the incessant change in the business environment on all fronts has always been proof of the need to gradually rethink how the organization is managed.

It was the trigger for the global experience with organizational management models, brought about by the transition from the Taylorian model of seeing the company as a whole, to a process system or "System composed of subsystems mutually influencing themselves through interactions and having their own objectives but working together towards a common goal" according to the work of researcher Jay W. Forrester.

We aim to enhance and implement the system approach in the sphere of improving the dependability of a production system, in order to synchronize optimizing the Safety, Reliability, Maintainability and Availability attributes to optimizing the maintenance cost for a system.

Keywords

System approach, improving the dependability of a production system, subsystems, interactions, optimizing the maintenance cost for a system.

1. Introduction

The system and the system analysis make the first stone of the systemic or the system approach. The latter is globalized on all the management levers of the organization, since the outline of the idea of the process system in the literature by very old thinkers and philosophers such as Blaise Pascal who proposed in his work "Les Pensées" in 1657 "So all things being caused and causing, aided and aiding, mediate and immediate, and all maintained by a natural and insensible link which binds the most distant and the most different, I hold it impossible to know the parts without knowing the whole, no more than knowing the whole without knowing the parts in particular. (Pascal et al., 2010)" until the concept approach process was integrated into the project of ISO 9001-2000 to serve, during the decade to come, a management system model for more than a million companies worldwide.

Today, the thought is to put the system approach in a cup of improvement of the maintenance of the production systems, indeed, it is important to develop the systemic and to widen its fields of application by deploying it to the development of the dependability components and ensuring the optimization of the maintenance cost of a system, and therefore contribute to improving the functional and economic performance of the company in a distributed and difficult context in terms of objectives.

Thanks to our systemic thinking based on the system approach, we were able to build:

- The general hierarchical diagram of a system with the classes of its subsystems and the interactions;
- Our hypothesis of safety of classes of subsystems and interactions;
- Our hypothesis of reliability and maintainability of classes of interacting subsystems.

2. Anchoring of concepts

2.1. The system according to the systemic

The system is generally defined by (Brandenburg and Wojtyna, 2006):

- *Borders (what is inside and what is outside):* It is the observer who determines where the system starts and stops, depending on the purpose of the analysis. What is system in one case of analysis can become subsystem or environment in another case.
For example, we can take a workshop or just a workstation (work position) as a system. This choice of boundaries will depend above all on the goal of our analysis: improving the entire workshop or optimizing a single workstation. If we choose the workshop as a system, the position will be an element, also called a subsystem. If we choose the position, the workshop will be its environment, which is sometimes also called macro-system.
- *Exchanges with its environment (what happens at its borders):*
 - ✓ Inputs that are a source from the environment;
 - ✓ The outputs which are the action of the system on its environment;
 - ✓ The transformation described by the difference in the state between inputs and outputs.
- *An interior with a set of elements linked together (the interacting subsystems);*
- *A certain stability (the system is maintained even in a changing environment):* This last characteristic leads to the notion of feedback or cybernetics; it is also called the feedback loop. It is an adaptation mechanism that ensures constant outputs and makes its good response even if the inputs or the environment fluctuate. The quality wheel (Deming wheel) or PDCA cycle is a derivative of this principle of feedback.

This principle is similar to the automatic control of a system, so the system can be modeled in general with its feedback loop in a changing environment thanks to the general block diagram below:

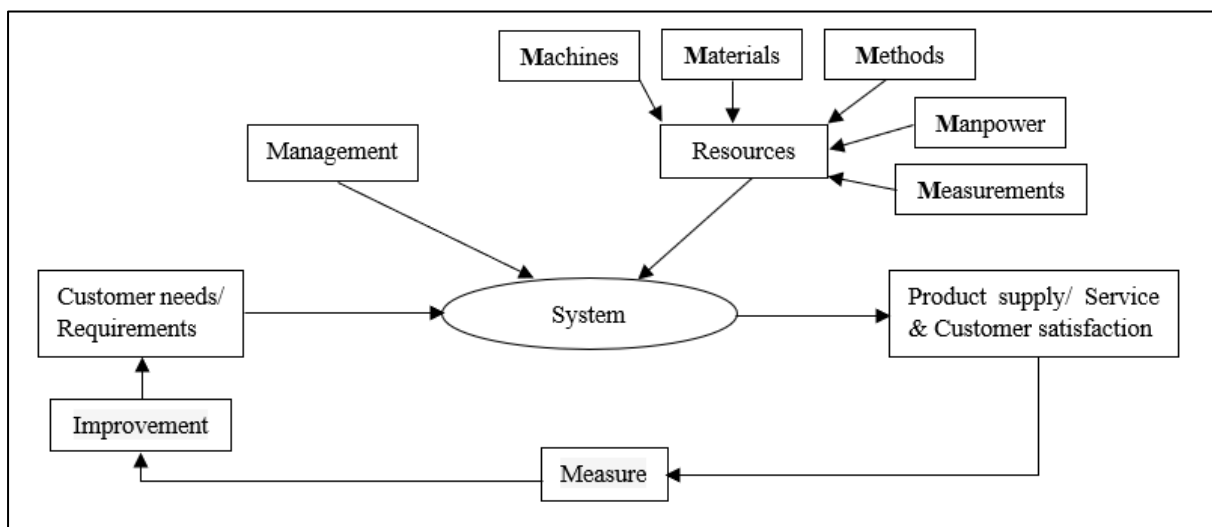


Figure 1. Block diagram modeling the stability of the closed loop system (feedback loop) in a changing environment.

For our research, the system in question is an activity, equipment or production unit with dependable subsystems to be improved by deploying the system approach.

2.2. System approach

The system approach (or systemic) is a multidisciplinary methodology. It has been developed and used in biology as well as in mathematics, psychology, sociology and robotics. It offers another way of looking at complex organisms and organizations, to better understand, predict and manage them. The process approach has taken over a number of concepts and methods from the systemic, that is why we will come later to present very briefly the system approach (Brandenburg and Wojtyna, 2006).

Until the dawn of the 1970s, many businesses were organized according to a Taylorian-style model, adapted to an environment where demand exceeds supply. Competition is not globalized and resources are readily

available (Sidi Mohamed Ben Abdellah University: Faculty of Sciences and Techniques of Fez, 2016). During this auspicious period of rapid growth, for many companies, it suffices to produce to ensure sometimes exponential development and the capitalization of capital. Indeed, for many companies, the management model used consists in monitoring mainly macro-economic indicators linked to profitability and growth (what R. Demeestère called in 1995, as a "profitability benchmark"). To summarize, if the financial components of the company are satisfactory (Turnover and Result), no organized investigation seems necessary since overall, the only factual elements available are satisfactory. However, certain deficient parts of the organization can penalize, in a hidden way, the overall result of the business without it being possible to really materialize these drifts (Institut Numérique, 2014). History anchors the role of the economic, political and social environment in leading the shift towards the system approach.

The first oil shock is a world crisis in oil prices which began in 1971 following the peak of oil production in the United States and the abandonment of the Bretton Woods agreements which resulted in a strong concentration of the depreciation of the dollar and therefore oil prices which are denominated in dollars. The occurrence of the 1st oil shock changed the situation. From the month of March 1974, the price of a barrel is quadrupled, going from 2.59 to 11.65 dollars, while the economic environment is sliding towards a crisis situation, companies have been obliged to rethink gradually in their management method (McVeigh, J. C, 1984).

Organizations must be more effective and efficient in order to be able to develop in a difficult context because of (Institut Numérique, 2014):

- Exacerbated competition is becoming globalized (Common Market, Low-Cost Countries in Europe, then in Asia) with the consequence of an abundance of products and declining margins;
- Energies are becoming expensive;
- Social, regulatory and environmental constraints are increasing.

Faced with this changing environment, the traditional Taylorian approach is no longer suitable (Institut Numérique, 2014):

- Human resources are called upon in such a way that the actors can no longer be reduced to simply carrying out tasks in a given time: proactivity, participation in problem solving groups, delegation of part of the responsibilities to the level production, require a different management from the mechanistic mode thought by Taylor (from classical thought);
- The products are personalized on shorter series (drawn flows): this requires flexibility, adaptability and superior skills on the part of men and business processes;
- The separation of tasks and services is no longer appropriate: short development cycles and complex products require a multidisciplinary approach and an effective collaboration of the skills implemented. Design, development, production and logistics activities must interface perfectly with each other, but also have an ever more proactive support for purchasing, human resources and quality. This therefore requires implementing a transversal organization where interactions are defined as precisely and reliably as possible. All supported by a clear vision, both of the overall strategy of the company, but also of the added value of each process making up the organization.

At the turning point of the 1970s and 1980s, many companies were therefore led to rethink the structure of their internal organization in order to adapt it to this new environment. This is probably why, from this time, the process approach will interest an audience of students, researchers and managers constantly growing. So much so that, in 1998, the concept was integrated into the ISO9001-2000 project, which will serve, over the next decade, as a management system model for more than a million companies in the world. The initial concept was developed by an Austrian researcher who emigrated to the United States, it is Ludwig Von Bertalanffy. As early as 1951, this researcher, through a major article published in the journal *Human Biology* under the title "General Systems Theory", set out an innovative concept of "complex of interacting elements" laying the foundations of the system approach. The idea of a process system interacting with each other is not entirely an ex-nilo creation of Bertalanffy. The latter relied on several thinkers and philosophers (sometimes ancient) who had already traced some of the main lines of the concept, starting with Blaise Pascal who proposed in "The Thoughts" in 1657 "So, all things being caused and causative, helped and helping, mediates and immediate, and all being maintained by a natural and insensible bond which binds the most distant and the most different, I wish impossible to know the parts without knowing the whole, no more than knowing the whole without particularly knowing the parties" (Institut Numérique, 2014).

After Pascal and Bertalanffy, this concept of "system" was later completed in 1975 by Joël de Rosnay who wrote "a system is a set of elements in dynamic interaction, organized according to a goal" (Institut Numérique, 2014).

Notwithstanding the contributions of its illustrious predecessors, it is however possible to affirm that the "General Systems Theory", as stated by Bertalanffy in 1951, developed and popularized the concept of "system" by adapting it to the approach scientist of the 20th century (Institut Numérique, 2014).

This concept, initially thought by Bertalanffy as a universal model that can be applied as much to inanimate objects as to computer programs, was then identified as a model that can be applied in principle to management

for companies. This translation into the sphere of organizational sciences was carried out by the work of researcher Jay W. Forrester at the Massachusetts Institute of Technology. The latter published in 1961 a work entitled "Industrial dynamics" which is the founding link between the General Theory of Systems and the world of business (Institut Numérique, 2014).

Concretely, for Jay W. Forrester, the company is no longer to be considered as a whole but as a system composed of subsystems influencing each other through interactions and having their own objectives but working together towards a common goal. So, to do this (Institut Numérique, 2014):

- The system is fed by input data. These may be, for example, financial resources and / or raw materials, technical or social requirements;
- The system distributes within it the various inputs to the component sub-systems. The subsystems then carry out their activities by interacting with each other;
- The system produces output data. It can be for example a product or a service;
- The performance of the individual activities of the subsystems and the interactions uniting them, determines the overall effectiveness and efficiency of the system.

Declined for organizations, the strength of the process approach is therefore to say (Institut Numérique, 2014):

- Let's no longer look at the organization as a whole;
- Neither do we look at the organization as a grouping of autonomous activities;
- Let's look at the organization as a set made up of interrelated entities interacting with each other and look in particular at the "quality" of these interactions because it is on these latter that the organizational performance will depend.

In practice, this partitioning of the system into subsystems (also called processes) makes it possible to study their interactions and understand how the achievement of the common goal is achieved. This therefore makes it possible not only to ensure control of the overall result, but also to clearly visualize the results of each sector of the company (Brandenburg and Wojtyna, 2006).

In 1973, in their reference work "Management systems (PUF)", Pierre Tabatoni and Pierre Jarniou, subscribe to this approach and write "It does appear that systems theory must make it possible to better understand and master the operation of Organizations, to go beyond the theories of Bureaucracy as well as the classic economic analyzes of the Firm". The definitions provided by the literature can also help us understand the concept. To begin with, ISO 9000 gives us the following definition "The systematic identification and management of the processes used in an organization, and more particularly the interactions of these processes, are called the process approach" (Institut Numérique, 2014).

More elaborately, ISO9001 §0.2 specifies "The Process Approach designates the application of a process system within an organization, as well as the identification, interactions and management of these processes with a view to achieve the desired result. One of the advantages of the Process Approach is the permanent control it allows over the relationships between individual processes within the process system, as well as over their combinations and interactions". According to Brandenburg and Wojtyna (2006), some authors complete the subject and give us their personal vision of the Process Approach, saying "The Process Approach is a method of analysis and modeling. It consists of methodically describing an organization or activity, generally with the aim of acting on it" (Institut Numérique, 2014).

Through the system approach, internal performance is materialized, weak processes are dealt with and strong processes are strengthened. By improving its components, the overall result of the organization improves. (Institut Numérique, 2014).

2.3. Before the system approach, what is system analysis?

Before the system approach, to study phenomena or problems, we know the method of Mr. Descartes "The Discourse on the Method" which is characterized by (Brandenburg and Wojtyna, 2006):

- *The precept of evidence:* Accept what is obvious for real;
- *The reductionist precept:* Divide the difficulties to solve them one by one;
- *The precept of causality:* Starting from the simplest to the most complex, from cause to effect;
- *The precept of exhaustiveness:* Measure everything exhaustively, to be sure not to forget anything.

This method already includes elements that we will find in system analysis, as presented by J.L Le Moigne in the four precepts of a "New Discourse on the Method" in his book "The theory of the general system" (Brandenburg and Wojtyna, 2006):

- *The precept of relevance:*
 - ✓ Define any object in relation to the explicit or implicit intentions of the observer;
 - ✓ Never refrain from questioning this definition if our intentions change or if our perception of the object changes.
- *The precept of globalism:*

- ✓ Consider any object as an immersed and active part within a larger whole;
- ✓ First of all, perceive it in its functional relationship with its environment;
- ✓ Not to be interested a priori in its internal structure, whose existence and uniqueness will never be taken for granted.
- *The precept of finality*: Interpreting the object by its behavior (and not in itself) without trying to explain this behavior by a law internal to its structure, but understanding its behavior and the resources it mobilizes in relation to purposes that the observer attributes to it.
- *The precept of relevance (or aggregation)*: Agree, deliberately, that any representation is simplifying and choose to consider only the elements considered relevant by the observer.

So, the system approach leads to focus first on the results and not on the means or the processes (Brandenburg and Wojtyna, 2006).

2.4. Dependability and its components

2.4.1. Historical

The term Dependability (meaning reliability, operating safety or dependability with a weak meaning compared to today) appeared in an advertisement for Dodge Brothers engines in the 1930s (according to the National Office for Aerospace Studies and Research - France). (ONERA, 2012)

According to A. Leroy and J.P. Signoret (Leroy and Signoret, 1992):

- The inter-war period saw the emergence of the concepts of reliability and failure rate in aeronautics following the comparison of the frequencies of breakdowns of twin and four-engine aircraft and the calculation of ratios, number of breakdowns/ number of hours flight;
- From the Second World War, a discipline developed under the name of ‘Reliability Theory’. The 1940s and 1950s were characterized by the discovery of the effectiveness of a probabilistic approach applied to electronics in aeronautics, defense and nuclear. The formulation of what seems obvious to us today - the probability of success of a chain of components is the product of the probabilities of success of each component - was the source of very rapid development in the fields mentioned. This period was also that of a rapid development of electronics which introduced numerous components whose individual failures are unpredictable at this stage of knowledge, but whose collective failures present statistical regularities; on a homogeneous batch of components, we know how to predict with good confidence the number of failures per unit of time that will occur while we remain completely incapable of predicting which component will fail and when;
- The 1960s and 1970s were marked by attempts to generalize this successful probabilistic approach to other ‘components’: mechanical, hydraulic, electrical, then to humans, to software ... and the extension of the approach to return to normal (reliability is added to maintainability). At the same time, methods are being developed to control the risks of complex systems (nuclear power plant, supersonic ...) and no longer simply of chains of components (even complex). These approaches are led by teams formed around the ‘Reliability Theory’. However, they are in line with the consideration of risks which has always accompanied risky activities such as transport. These activities, from their earliest youth, had to control the risk of accidents. They developed very advanced deterministic approaches and mainly relied on oversizing, redundancy and logical analysis to ensure security. The contribution of probabilistic approaches makes it possible to seek to adjust the prevention measures for random events instead of remaining sheltered behind large and costly sizing standards;
- From the 1980s, efforts undertaken in so many directions deepened, but also tended to come together to constitute this very wide field of application that is today dependability. We note the following developments:
 - ✓ Constitution of reliability databases;
 - ✓ Beginning of standardization in terms of dependability;
 - ✓ Development of methods of analysis, modeling and representation of complex systems;
 - ✓ Development of calculation software;
 - ✓ Development of modeling software;
 - ✓ Test campaigns to collect reliability data;
 - ✓ Widespread or targeted use of dependability in most industries;
 - ✓ Use of dependability to control all types of industrial risk (and little by little legal, individual, financial risks, etc.) and not only safety;
 - ✓ Appearance and development of contractual dependability clauses and legal and regulatory requirements for dependability;
 - ✓ Growing need for advanced knowledge in the scientific fields concerned in complex systems: programmed systems, human and social sciences.

Today, the term “Dependability” covers all the means which allow one to give oneself and transmit a justified confidence in the success of a project, an activity and its safety (Mortureux, 2001).

The current concept of dependability can be defined by “all of the capabilities of an entity allowing it to have specified functional performance, at the desired time, for the expected duration, without damage to itself and to its environment (Chevance, 2001)”.

The objective of dependability is to reach the Grail of system design: zero accidents, zero stops, zero faults (and even zero maintenance). (ONERA, 2012)

2.4.2. Maintainability, Reliability and Safety for Availability

2.4.2.1. Maintainability and Reliability for Availability

Maintainability has real design features. Attempts to improve the inherent maintainability of a product or article after the design has frozen are generally costly and ineffective (NASA, 2008).

In the “Military HandBook” work, the maintainability represents the ability of a system to be maintained or restored to a specific operating state, when maintenance is carried out by personnel having the required skills and using the procedures and prescribed material resources. In other words, it represents the ease and speed with which a system can be restored to working condition after a failure. We find in the literature several references, (Dhillon, 1999), (Dhillon, 2002), (Ebeling, 1997), (Military HandBook - 791, 1988) or (standard NF X60-301, 1982), which present the criteria which give a system a good level of maintainability (Nabdi and Herrou, 2016).

Kapur and Lamberson define maintainability as “the probability of a device being maintained or restored under given conditions, during a given time interval”. According to the AFNOR X 60-500 standard, maintainability is “the ability of an entity to be maintained or restored, over a given time interval in a state in which it can perform a required function, when maintenance is performed in given conditions, with prescribed procedures and means”. An equipment is maintainable if it can be repaired quickly. Repair is all basic recovery operations including logistical delays. Maintainability refers to the speed of repair tasks while reliability is concerned with reducing the number of failures (Nabdi and Herrou, 2016).

Poor maintainability results in unavailable equipment which is expensive and results in an irritable condition for all parties involved with the equipment (NASA, 2008).

Reliability and maintainability are seen as complementary disciplines to the inherent availability equation. Inherent availability examines availability from a design perspective (NASA, 2008):

$$D_i = \frac{MTBF}{MTBF + MTTR} \quad (1)$$

Or:

- D_i : Inherent availability (Disponibilité inhérente in French);
- $MTBF$: Mean Time Between Failure, it is the average of the times between two successive failures;
- $MTTR$: Mean Time to Repair or Replace, it is the Average of the Technical Repair Times.

If MTBF is very large when compared to MTTR, availability will be higher. As reliability decreases (i.e., the MTBF becomes smaller), better maintainability (i.e., shorter MTTR) is necessary to achieve the same D_i . As reliability increases, it is not as urgent to improve maintainability in order to achieve the same D_i . Tradeoffs can be made between reliability and maintainability to achieve the same D_i . Reliability and maintainability must work closely together to achieve general maintainability objectives. D_i is the greatest observable availability value assuming no misuse of the system or process. Operational availability looks at availability by collecting all of the abuses in a practical system (NASA, 2008):

$$D_o = \frac{MTBM}{MTBM + MDT} \quad (2)$$

Or:

- D_o : Operational Availability (Disponibilité opérationnelle in French);
- $MTBM$ (Mean Time Between Maintenance): It is the average of the times between maintenance;
- MDT (Mean Down Time): It is the Average of the downtime.

According to the NASA (2008), the MTBM includes all corrective and preventive actions; MTBF only accounts for failures. The MDT includes all time associated with the system being down for corrective maintenance including delays (MTTR only addresses repair time) and self-imposed downtime for preventive

maintenance. D_o is a smaller availability number than D_i because of naturally occurring abuses. The following should be included in the time-to-repair calculations:

- Time to successfully diagnose the cause of the failure;
- Time to procure or deliver the parts necessary to perform the repair;
- Time to gain access to the failed part or parts;
- Time to remove the failed components and replace them with functioning ones;
- Time to bring the system back to operating status;
- Time to verify that the system is functioning within specifications;
- Time to “to close up” a system and return to normal operation.

The following table illustrates the standard definitions of reliability and maintainability terms determined by the NASA (2008):

Table 1. Maintainability Metrics.

Measure	Description
Mean Time to Repair (MTTR)	The arithmetic average of the maintenance cycle times for the individual maintenance actions of a system (excludes preventive maintenance).
Mean Preventive Maintenance Time	The arithmetic average of the maintenance cycle times for the individual preventive maintenance actions of a system (inspection, calibration, planned replacement, etc.).
Median Active Corrective Maintenance Time	The value of corrective maintenance time that divides all downtime values for corrective maintenance so that 50 percent are equal or greater than the median.
Mean Active Maintenance Time	The arithmetic average elapsed time needed to perform maintenance (both preventive and corrective) excluding logistic and administrative delays.
Maximum Active Corrective Maintenance Time	That value of downtime below which one can expect a specified percent of all corrective maintenance to be completed; must be stated at a given percentile, usually 90 or 95; primarily related to a lognormal distribution.
Mean Time to Restore System	For highly redundant systems, this is the time need to switch to a redundant backup unit.
Mean Down Time (MDT)	The arithmetic average time that a system is not operational due to repair or preventive maintenance. This includes logistic and administrative delays.
Maintenance Labor Hours per Hour/Cycle/Action/Month	A measure of labor hours expended (based on operating or calendar time, maintenance actions, or operating cycles).

2.4.2.2. Safety for Availability

According to *standard EN 292-1 on Safety of machinery - Basic concepts, general principles of design - Part 1: basic terminology, methodology*, the safety of a machine is its ability to perform its function, to be transported, installed, developed, maintained and disposed of under the conditions of normal use specified in the instructions, without causing injury or damage to health (Norme EN 292-1, 1991).

It is the ability of a system not to generate, under given conditions, critical or catastrophic events. To get started and give an example in terms of the safety component, this part has just highlighted the basic concepts of safety:

- *Hazard (source of risk)*: Source or situation which may cause injury, damage to health, damage to material or the environment at the workplace, or a combination of these (OCP Group, 2013);
- *Risk*: Probability, expressed either in probability or in frequency, of a danger materializing (Dr. J. Smith, 2011). It is the combination of the probability of the occurrence of one or more dangerous events, the severity of the damage likely to be generated and the frequency of exposure to this dangerous event (OCP Group, 2013);
- *Incident*: Any event which could have led to material and/ or bodily and/ or environmental damage (OCP Group, 2013);
- *Accident*: Any event which has led to material and/ or bodily and/ or environmental damage (OCP Group, 2013);
- *Damage*: Consequence of the accident (realization of the Risk) (OCP Group, 2013).

These are definitions extracted from the Standard of Risk Analysis of the OCP Group, in view of our experiences with this industrial group and its commitment to excellence in HSE (Hygiene, Safety and Environment) which has been awarded by obtaining a gold medal from the International Fertilizer Association (IFA) on Wednesday, November 14, 2018, on the sidelines of the IFA Strategic Forum in Beijing, China (Newspaper Le Site Info, 2018).

Reducing and even eliminating the hazards of a system leads to a reduction in risks, and therefore a reduction in the number of incidents, the number of accidents and the damage likely to take place. This directly contributes to the optimization of the average downtime (MDT) and therefore to the optimization of the availability component.

3. Our systemic thinking to improve dependability through the system approach

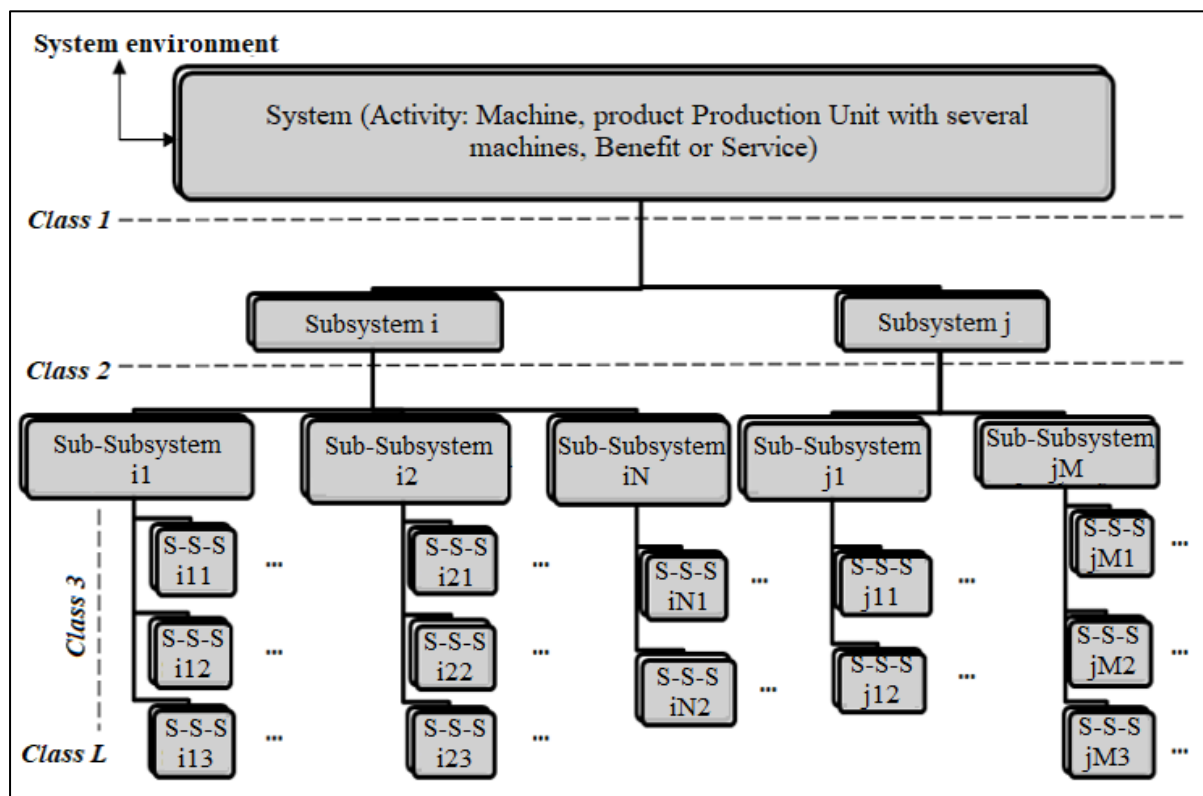


Figure 2. General hierarchical diagram of a system with the classes of its subsystems and the interactions.

This is the basic diagram of our hypotheses for improving dependability through the system approach. We carried it out as part of our research work, to the extent of putting it the first stone of our critical thinking leading to the taking into account of the system approach in the optimization of the attributes Safety, Reliability, Maintainability and System availability.

So, through our dynamic vision of the system approach attached to systems thinking:

- The system includes classes of subsystems and internal and external interactions;
- Each class has subsystems and their interactions;
- Each subsystem of class k (with $k > 1$) can be composed by one or more subsystems of class $k + 1$.
 Example: according to the general hierarchical diagram of the system in the figure above, class 1 is composed of the subsystems i and j . And:

✓ In class 2:

- $i1, i2, \dots, iN$ are Sub-Subsystems of the whole System, because they are subsystems of the subsystem i of class 1;
- $j1, \dots, jM$ are Sub-Subsystems of the Whole System, because they are subsystems of the subsystem j of class 1;

✓ In class 3:

- $i11, i12$ and $i13$ are Sub-Sub-Subsystems of the Whole System, because they are subsystems of the Sub-Subsystem $i1$ of class 2;

- i21, i22 and i23 are Sub-Sub-Subsystems of the Whole System, since they are subsystems of the Sub-Subsystem i2 of class 2;
- iN1 and iN2 are Sub-Sub-Subsystems of the Whole System, since they are subsystems of the Sub-subsystem iN of class 2;
- j11 and j12 are Sub-Sub-Subsystems of the Whole System, because they are subsystems of the Sub-Subsystem j1 of class 2;
- jM1, jM2 and jM3 are Sub-Sub-Subsystems of the Whole System, because they are subsystems of the Sub-Subsystem jM of class 2;
- ✓ In the same way up to class L;
- For each class of the hierarchical diagram of a system, the number of SUBS associated with the word system (for the subsystems of all the classes) is equal to the level of the class of the subsystem compared to the Target System or whole, making the top of the hierarchical diagram, therefore, it must take the name ‘‘Subsystem X of class $k \geq 1$ ’’: for example, in figure 2:
 - ✓ The subsystem i12 of class 3: is a SUB-subsystem of the whole system;
- *The internal interactions are:*
 - ✓ Those between the classes of the subsystems (see Figures 2). They are called *the interactions between two successive classes*. Example: class 1 and class 2 are linked by:
 - The interaction between the subsystem i of class 1 and its subsystems i1, i2 ... iN of class 2;
 - The interaction between the subsystem j of class 1 and its subsystems j1 ... jM of class 2;
 - ✓ *The interactions between subsystems of the same class* (see Figure 2).
- *The external interactions* are those between the system and its environment.

The general hierarchical diagram of a system has enabled us to draw up two hypotheses for improving dependability which formed the basis for the development of two system approaches, one applied to safety and the other to reliability and maintainability attached to the cost of maintaining the system:

- *Hypothesis of safety of classes of subsystems and interactions (hypothesis $n^{\circ} 1$)*: This is the hypothesis of our ‘‘System Safety Approach’’. Thanks to a global vision of the system allowed by the systemic, we can say at first, that the improvement of the fourth component of dependability of a system which is its safety requires the improvement of all classes of sub-systems as well as the interactions in matters of this component, from the base of the hierarchical diagram to the subsystems of the 1st class, and it is by following the critical path of safety, composed of points of concentration of the latter, and which are the subject of its evaluation to all the hierarchical classes of the subsystems of the system in question. In a second time, we can say that the level of importance or criticality of the interactions follows an ascending arrow (from bottom to top) on the general hierarchical diagram of a system (see Figure 2), indeed, the interactions as well as the classes of the closest subsystems at the top of the hierarchical diagram of a system are the most critical in terms of safety:

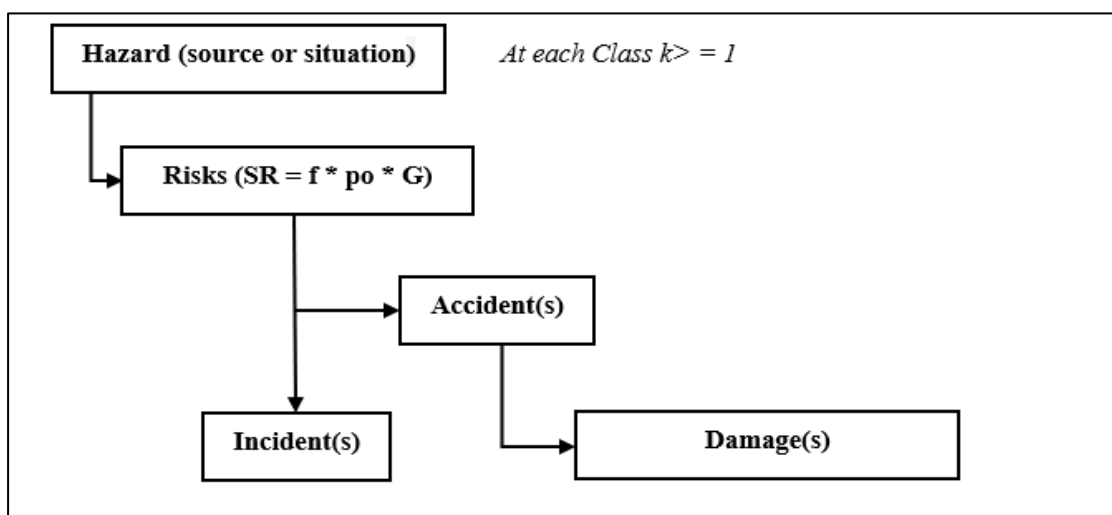


Figure 3. Critical safety path of a system to each class of subsystems.

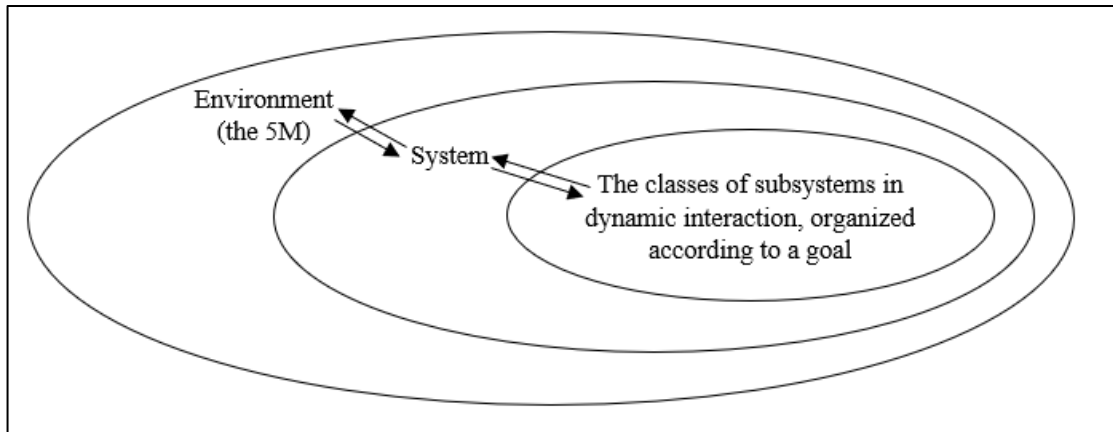


Figure 4. The internal and external interactions of a system.

As remark, the 5M making the environment of the system are: Methods, Materials, Machines (equipment's, technology's, etc.), Manpower and Measurements, in fact, they are sources of risks (they are hazards) with which it is external interactions. However, in any risk analysis tool, the work instructions (as elements of Methods, and which are among the means of risk prevention) are always excluded and separated from the risk analysis plan, since they are items under the responsibility of operation or production service (or department) and not that of safety within the company! But thanks to the system approach, the company is a process system in dynamic interaction, which helped us to achieve a new risk analysis tool including *the work instructions (les modes opératoires in French)*, and this is what will be an article unifying and common between the production service (or operation as an implementing process) and the safety service (as a support process) in the company.

- *Hypothesis of reliability and maintainability of classes of interacting subsystems (hypothesis n ° 2):* This is the hypothesis of our "System Reliability and Maintainability Approach".

Thanks to:

- ✓ A dynamic and global vision of the system allowed by the systemic, in fact, attached to a systemic thinking opposite with that analytical (classic or cartesian-analytical);
- ✓ an exhaustive definition of the new system paradigm defined by the systemic, this is the definition was given by Joël de Rosnay who wrote in his treatise "The macroscope: towards a global vision": "a system is a set of elements in dynamic interaction, organized according to a goal (Rosnay, 1975)";
- ✓ our general hierarchical diagram of a system showing the classes of its subsystems and the different interactions (see Figure 2).

We can say that:

- ✓ The level of importance or criticality of interactions follows an ascending arrow (from bottom to top) on the general hierarchical diagram of a system (see Figure 2), indeed, the interactions as well as the classes of the subsystems closest to the top of a system hierarchy are the most critical in terms of dependability in general and reliability and maintainability in particular;
- ✓ The system includes several classes of subsystems in dynamic interaction and according to an order guaranteeing the balance and the characteristics of the normal functioning of the system, under the system immediately there is the 1st class, it is the set of subsystems and internal and external interactions making the test body (the element in direct contact) for their system, and therefore the optimization of their reliability, maintainability and maintenance costs immediately generates optimization of the system;
- ✓ The optimization of these dependability components (reliability and maintainability) of a system can be drained attached to the optimization of the maintenance costs of its subsystems in dynamic interaction and organized according to the purpose of the whole which is the system. This is what formulates:
 - The main objective of our new approach which is "the System Reliability and Maintainability Approach" based on mathematical programming;
 - The problem of optimizing two families of aspects (dependability performance & maintenance costs) with opposite directions of improvement.
- ✓ For any system (machine or production line) studied with N interacting subsystems in the 1st class, each of these has:
 - Reliability and maintainability (therefore an availability) to optimize (to maximize);

- An optimal (minimum) maintenance cost, estimated and objective for the responsible service during a well-defined time interval.

Question asked! What are the optimal (maximum) values of reliability and maintainability that must be available for each interacting subsystem of 1st class of the studied system? Under the constraints:

- ❖ Objectives of the responsible service in terms of the costs of maintaining the subsystems to be minimized;
- ❖ Objectives set by the management responsible for the reliability and maintainability of the system studied.

4. Conclusion

As part of our research perspectives, with a view to improving the dependability of a system and minimizing its maintenance cost, we first thought of a first new system approach applied to the safety called ‘‘System Safety Approach’’, then to a second which is called ‘‘System Reliability and Maintainability Approach’’ in a second time.

The first approach is based on our hypothesis of safety of classes of subsystems and interactions according to the general hierarchical diagram of a system, making the reference of our development of a new tool called ‘‘the plan of Microscopic Analysis of Risks related to Classes of Subsystems (or MARCS plan)’’. The ‘‘MARCS plan’’ is the first and only tool combining the work instructions and the risk assessment in a single article (document common between two distinguished processes) of the company. It is the realization of the system approach in matters of safety control, which calls upon the versatility of the personnel of the company, the centralized implication on all the personnel of the company and all the hierarchical lines other than that responsible for safety, to the mutual influence between the safety component and the other components of the same organization, to the significant optimization of the risk scores of an activity, and more particularly to the enrichment of the synergy and the good coordination between two distinguished services (processes or sections) which are normally:

- The safety process, which is usually responsible for the risks analysis in a document bearing a well-determined code at the company level;
- The operating, production or any implementing process which is usually responsible for developing the work instructions necessary for an activity at the level of a product or service production entity (on an independent document, bearing a code determined and separated to the risk analysis document in the company!).

The second approach makes the bridge from the Mathematical Programming discipline of Operational Research science to dependability of a system, with the objective of optimizing the reliability and maintainability components of its subsystems in dynamic interaction in the 1st class and minimize the costs of their maintenance.

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