Design for reliability: an application to natural gas pipelines

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Abstract:This work presents a systematics of product project for reliability. It aims at structuring a model which takes into account the concept of reliability in the project process, particularly in informational and conceptual project stages. The proposition has been applied to a mains gas project in the metropolitan area of Curitiba, Paraná, Brazil. Through its application, it was possible to highlight the importance of understanding the existing principles and correlations in the attribute reliability for the project process. In order to do so, some points have been considered: the meaning of the terms which make up the definition of reliability; the correlation with project process stages; and the way of classifying the activity to guarantee reliability along the life cycle. The work also presents information regarding the failure rate of the items used in the mains, the reliability model and the alterations recommended for the mains conceptual project, aiming to increase reliability in gas supply for consumers.
Keywords: Design for reliability, natural gas pipelines.

1. Introduction

This work presents a systematization of product project for reliability which is applied to the informational and conceptual project stages. However, since reliability is strongly dependent on a product's duty cycle, it is necessary to consider it in all phases of the life cycle.

Several attributes must evidently be considered when developing a product: reliability, maintainability, human factors, safety, availability, assemblability, logistic, economic factors, among others. The management of the several attributes demanded for a product project must be carried out in a way that balances all attributes according to market demands, norms, legislation and strategies needed for a successful enterprise.

Bearing these aspects in mind, this work intends to present decisions and results reached in the project process, during the stages of informational and conceptual project for mains gas in the metropolitan area of Curitiba, Paraná, Brazil. During these stages, parameters – which must guarantee the product reliability demanded along its life cycle – were defined, according to expectations of the product's consumer market.

It is necessary to define, in the first phases of the life cycle, the metrics to be considered, so that reliability demanded along the life cycle can be guaranteed. However, it is during the project process that the set of variables, defined in the previous phases, is implemented: business and product planning. The agents who develop the project process need to know, in a very detailed manner, every aspect associated to reliability, so that these considerations can be taken into account. Such aspects involve: definition of reliability, the meaning of its constitutive terms, as well as how linked they are to the several stages of the project process, to reliability measures, to reliability models and to mathematical representations.

2. Definition of reliability

Reliability is the attribute characterized by the probability of a product fulfilling its function along its life cycle. It is usually confused with quality, an aspect which is strongly related to standards of products' performance.

There are various definitions for reliability. As a whole, reliability can be defined as the probability of an item performing a certain function, in an adequate manner, during a given period of time and under specific conditions. It is important to comprehend that the definition of reliability must have four fundamental structures or categories: **probability, adequate behavior, duty cycle, and use conditions** (DIAS, 1996). These categories and their meanings must be fully considered in each phase of the product's life cycle, especially during the project process, as well as in the analysis of the activity, so that reliability can be guaranteed.

◆ **Probability** expresses the possibility that an event might occur. There is no simple formula or technique to analyze it: it depends on the existing problem and on established constraints. Difficulties in considering this structure take place mainly during the first phases of product development, and virtually in all stages of the project process. They are due to lack of information concerning statistically relevant quantity and quality, as regards the event in focus. In these cases, analysis strategies and tools need to be used. They must be compatible with the demands imposed by decision-making, recommended for each phase of the life cycle. In the light of statistic data and following appropriate formulations, references can be established; these references must be followed in each phase of the life cycle, or in each phase of any of the stages.

◆ **Adequate behavior** indicates the existence of a pattern, a referent to be aimed at or previously defined. That is to say that in those cases in which information is available, the pattern is established a priori. When data do not exist, on the other hand, goals are established a posteriori. In some cases, there is the need for considering methods which can transform qualitative information into quantitative information, so that reference is created to work as the basis during the whole life cycle of the product. Depending on the sort of market, the pattern may be obtained through marketing, technical norms, contractual or governmental demands, environmental laws or failures reports.

◆ **Duty cycle**, usually expressed in time functions, must be analyzed under the basic premise that failure will come, sooner or later. It is made up of sets of information which represent market expectations as regards the life of the item. This category turns the projector's attention towards solutions related to methods of avoidance, prevention and accommodation of failures. The projector must use redundancy techniques, failure forecast sensor, and even support management recommendations. The attribute maintainability gains in importance when reliability is focused from the viewpoint of this category.

◆ **Operation condition** refers to the adequacy of use environment to the project variable previously established. This condition needs to be well defined, since the success of an event might not be maintained if those premises previously established are altered. This category is situated in a phase of the life cycle called use or operation. The operation condition is related to technical and human aspects. That is to say that the formation and qualification of operating agents are fundamental conditions for guaranteeing reliability.

Reliability is also defined or represented by a mathematical expression. The mathematical expression is a codification whose goal is to synthesize an informational set or report, in a given percentage, aiming to facilitate project and/or management decisions. Evidently, there are various calculation possibilities when there are statistic data, but there also needs to exist a given mathematical formalism in order to represent them.

Mathematically, reliability R(t) is defined as the probability that an item will not fail between an initial time (t_o) and a final time (t), considering that the item is acting since the initial time (t_o). The complement of the function reliability, denominated cumulative probability function F(t), is the probability that the item will fail in the same time interval ($t - t_o$). The probability of one or another event happening, at any time t, is 1. Thus

$$R(t) + F(t) = 1 \qquad 1.1$$

The function F(t), depending on the application, is more frequently represented by the Weibull distribution and Exponential. Normal, Log-Normal, Poisson or Binomial distribution may also be used.

The distribution postulated by WEIBULL (1939) is the one which best represents the event related to the failure rate of the technical system. It allows for representing the failure event in the three most meaningful periods of the product's life cycle, characterized by the failure rate curve (Bathtub Curve) as: infant mortality, life span, and wear out or disposal period. Exponential distribution, with its constant failure rate, is adequate to represent life span. Normal distribution might be used to describe the wear out or disposal period.

Due to the various formulations presented by Weibull between 1939 and 1964, according to HALLINAN (1993), there might occur some confusion in the analysis or reading of results based on Weibull distribution. HALLINAN (1993), when revising Weibull distribution, presents the five cumulative probability function formulations F(t) and the corresponding functions of probability density f(t), instantaneous failure rate h(t) and the process to estimate Weibull distribution parameters, which are the five most used formulations in engineering areas.

The five most current formulations of cumulative probability function, according to HALLINAN (1993), are:

$$F(t) = 1 - \exp\left\{-\left[\frac{t-c}{a}\right]^{b}\right\} \qquad 1.2$$

$$F(t) = 1 - \exp\left\{-k(t-c)^{b}\right\} \qquad 1.3$$

$$F(t) = 1 - \exp\left\{-\frac{(t-c)^{b}}{k'}\right\} \qquad 1.4$$

$$F(t) = 1 - \exp\left\{-\left[a'(t-c)\right]^{b}\right\} \qquad 1.5$$

$$F(t) = 1 - \exp\left\{-\left[\frac{t-c}{a}\right]^{1/b'}\right\} \qquad 1.6$$

parameters being:

a is the scale parameter; in some cases, it is similar to the mean time between failures. In Weibull's equations, **a** used to be originally represented by σ_o, then by x_o, and, finally, by β.

a' = 1/a is analogous to the scale parameter for failure by time unit.

b is a form parameter which determines the distribution appearance or form. Weibull has represented it as **m**.

b' = 1/b is also a parameter which Weibull originally presented as **a**.

c is a local parameter. Weibull originally represented it as $\mathbf{a_u}$, then as $\mathbf{x_u}$ and finally as $\mathbf{x_o}$. It is the shortest time from which failure probability is not zero.

k is a parameter (not denominated by Weibull) which combines form and scale parameters.

k' = 1/k is also a scale parameter, but is influenced by the form parameter **b**.

Weibull distribution parameters can be determined by: 1 – a method based on Weibull's probabilistic role in which a scale with linear distribution data is defined; 2 – use of the least squares method, and graphical representation of information in a normal scale; 3 – theoretical determination through probability estimation methods. The two first methods are adequate for most applications (HALLINAN 1993, DIAS 1996).

The calculation of reliability, in each phase of the life cycle of the product, is related to the existence of organized information – defined by expectations of the market in which the product will be used-as well as to the existence of data, particularly those regarding product failures (figure 2). The failure register is more frequently found in components or systems with well-defined project and use patterns, like electronic, hydraulic and pneumatic systems. In these cases, it is easier to represent reliability by a statistic distribution. Weibull distribution is adequate for these cases.

Some other cases present a more complex situation: in new projects; when statistically meaningful failure rate registers are not available; or when components' failure rate estimation is not available, as in the case of mains gas in the area of Curitiba. In a situation like this, it is recommended to use exponential distribution, since its definition is based only on life span and failure rate. Failure rate, in these cases, is the reverse of mean time between failures (MTBF). Exponential distribution is a special case of Weibull distribution, when the form parameter equals 1. When calculating reliability for the mains gas components and systems, the local parameter c was considered as zero, that is, so small that it does not influence reliability in relation to the mains components and the life span of the systems. Thus, the equation of cumulative probability function F(t) for the exponential distribution used in the mains gas project is:

$$F(t) = 1 - \exp\left\{-\left[\frac{t}{a}\right]\right\} \qquad 1.7$$

When calculating reliability, the following concepts were considered: the concept of equivalent component – for the set of components plus sensor; the concept of reduced component – for the set of components interlinked in series; full parallel, partial parallel and complex interlink (DIAS, 1996).

From the first mains' configurations, still at the conceptual level, the reliability model was structured for each configuration.

3. Product life cycle and project process

A product life cycle involves a set of phases which can be briefly classified as: market demands, product planning, project process, production, consumption and disposal. There are several attributes to be considered during a product development as regards its life cycle. Some of these attributes are important in a given phase of the life cycle, or in some stages of each phase.

Reliability, in particular, is an attribute which must be considered in all phases of the life cycle. Lack of investments to guarantee reliability in the phase of production, for instance, has caused immense damages. In some technical systems of several areas – nuclear, aerial/spatial, petrol, electric energy – this sort of non-investment has caused damages of catastrophic dimensions, affecting companies, communities, environment, and even the development of those nations in which the failure process took place.

Project process is the phase of the life cycle that uses information, which has been organized during the development planning, in order to transform it into a technical system. Process project, according to Back & FORCELLINI 1997, OGLIARI 1999, FONSECA 2000, can be defined as a set of synthesis and analysis activities. It develops, basically, in four stages: informational stage, in which information is systematized; conceptual stage, in which the concept(s) regarding the product is/are generated; preliminary stage, which evaluates the generated concept and produces a preliminary analysis; and the detailed stage, in which all communication - between the necessary parameters for the manufacturing and use/disposal stages – is defined. In each stage, reliability is considered in a way which can be kept in the other phases of the life cycle, as presented in figure 1.

In the mains gas project, however, it could be seen that it is hard to manage all information and use the available tools to highlight reliability. In order to classify demands and requirements related to reliability, the Quality Function Deployment Matrix (QFD) has been used.

A product project is a process that involves several attributes, besides reliability. It is also known that there are strong inter-relationships among attributes: either in a direct or in reverse way. Important questions come about: how can

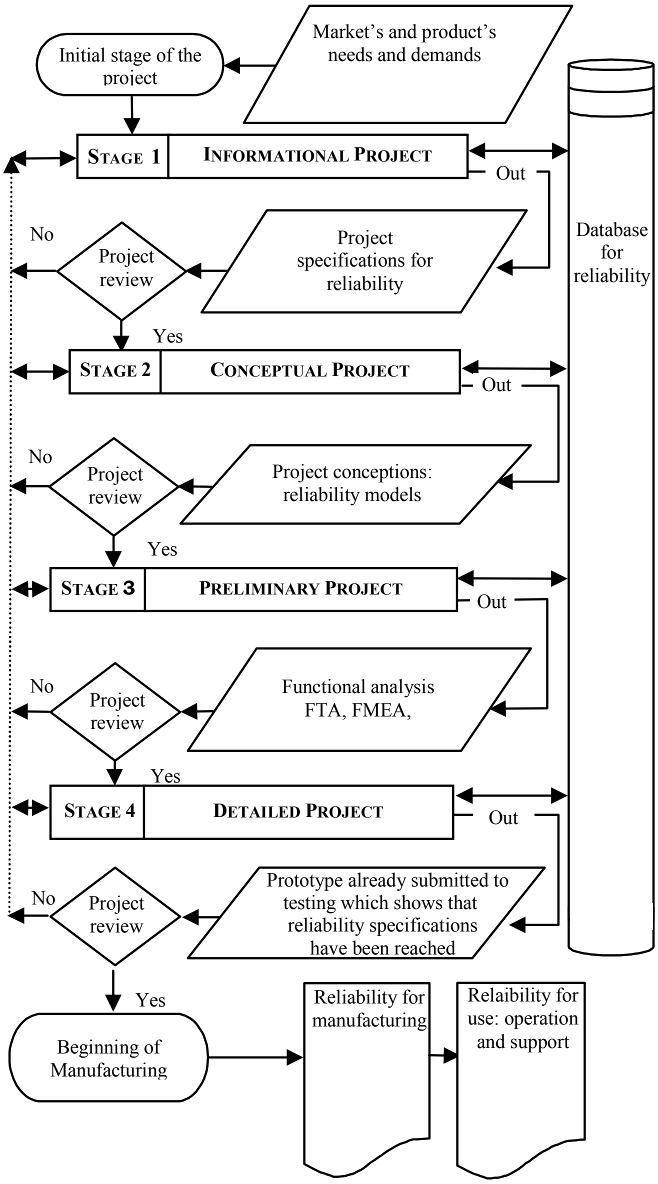


Figure 1 – Systematization for considering reliability in the design process.

reliability be considered in the project process; and how can it be maintained in the life cycle?

In order to approach these questions, the mains gas application has been structured under three aspects: the first one is based on a general view of the project process (figure 1), used to rationalize decision-making. The second one works as a reference to guarantee reliability in the life cycle of the product (figure 2), to the extent that the market defines external demands – such as norms, legislation, life span; the product itself defines concrete actions to be implemented in order to meet market demands. The third aspect, already

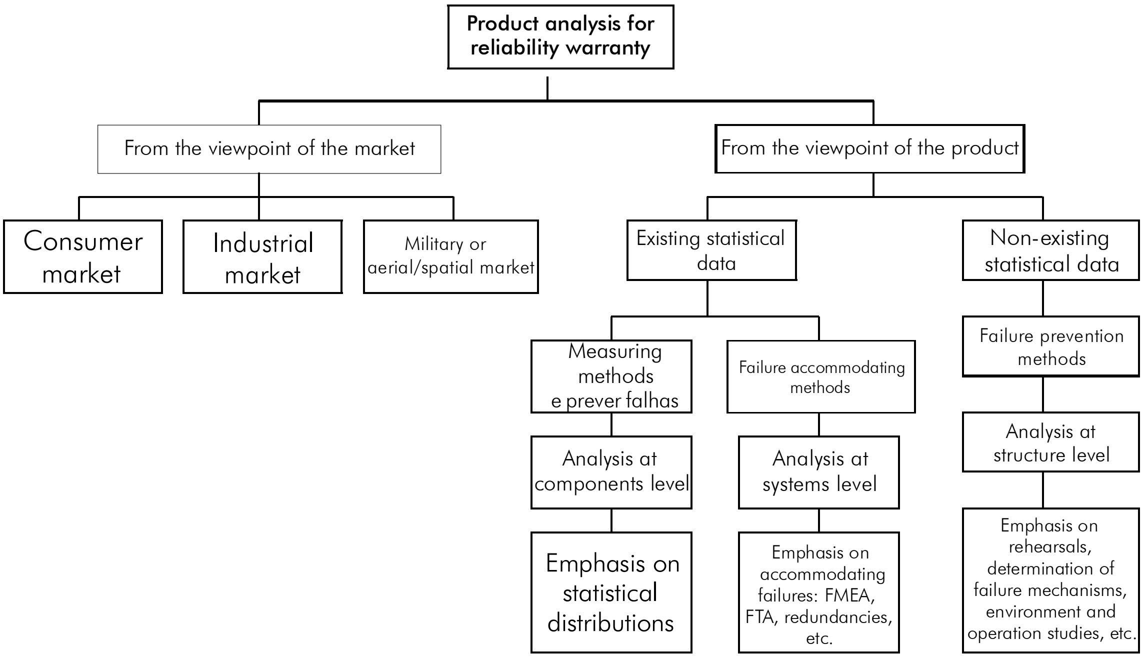


Figure 2 – Parameter for the analysis of reliability warranty, according to market and product information.

presented, is centered in comprehending the notion of reliability, and in its mathematical representation.

Figure 2 presents a model of analyzing the product to guarantee reliability – from the viewpoints of both the market and the product. This analysis was systematized by SANTOS (2001), based on studies presented by CONDRA (1993). This classification is a way of rationalizing the variables – reliability, norms demands, legislation, analysis tools – in each field of application.

In order to guarantee reliability from the viewpoint of the market, that is, according to market demands, products are classified in three levels: **consumer market, industrial market and military or aerial/spatial market**. **Consumer market** is that market which deals directly with the population as final clients. For these clients, reliability is confused with quality – in this case, reliability equals temporal quality. In this category, we can find, for instance, industries of domestic appliances, vehicles, goods in general – whose products have a direct relation with the consumer, the individual. Failures control is performed in the warranty period, but duty cycle is also fundamental for consolidating the product in the market. In the **industrial market**, industries supply other industries with items. With subsidiaries, this market became more dynamic and complex. A failure in a product of this market may affect not only the product, but also production itself. Costs are higher and reliability is usually defined in signed agreements. Automotive and electric industries, for instance, represent this market whose agreements have terms directly linked to reliability (NBR 6534 – 1986, NBR 9320 – 1986, NBR 6742 – 1987, NBR 5462 – 1994). **Military or aerial/spatial market** is characterized by specific demands and norms like, for instance, the American military norms (MIL-STD-1629A 1980, MIL-HDBK-218R 1991, MIL-HDBK-781A 1996). Failures in products of this market have very high costs and involve legal responsibility. Failures in some fields of this market affect not only the company in which failures have occurred, but also the whole industry in this sector.

For instance, a failure in a nuclear generating station causes problems for all plans of energy production, affecting also governmental decisions. Sectors which are part of this market include: military and aerial/spatial sectors, energy sector, petrol and gas sectors, chemical and petrochemical industry sectors.

Management aspects involved in this analysis precede the project process phase. According to the product characterization, which is defined by the market, a set of tools is selected; this set of tools will assist the project process stage, as well as the following phases (CONDRA 1993, SANTOS 2001).

In order to guarantee reliability from the viewpoint of the product (figure 2), it is necessary to know whether there are data for statistic analysis or not. When statistic data exist, that is, when there is a failures register with enough data to determine reliability, one of these paths can be followed: methods to measure and predict failures, or methods to accommodate failures. When statistic data do not exist, the use of methods to prevent failures is recommended.

Methods to measure and predict failures are adequate for estimation of failures in time, through analytical representations. In this sense, the focus turns to the study of each component which constitutes the system, processing information through probability distributions and determining parameters such as failure rate, mean time between failure and form parameter.

Methods to accommodate failures present an intermediary focus: between methods to measure and predict failures and methods to prevent failures. Their characterization is due to the fact that, in principle, the occurrence of failures in some items is admitted, but there is an attempt to diminish the effect of these items on the function. In order to do so, redundant systems may be used in the form of: active redundancy, passive redundancy, and sensors to detect those effects which denounce the presence of failure modes which, on their turn, can affect the function. This process is more appropriate for systems project or subsystems. In this case, some tools or analysis processes are recommended, such as: reliability models, redundancy criteria, failure mode effects analysis (FMEA), failure mode effects and criticality analysis (FMECA), fault tree analysis (FTA) (SANTOS 2001, SAKURADA 2001).

The methods to prevent failures are used when statistic data do not exist. In this method, several actions might be demanded to guarantee product reliability. At the level of systems, tools of analysis, which identify the failure critical path, must be used, such as: cause-effect relations, Ishikawa's diagram and fault tree analysis (FTA). When using methods to prevent failures, a number of elements should be known: all system items, operation environment, each item function in the system. Thus, possible failure modes and mechanisms can be identified. In this case, it is recommended that a functional analysis be carried out. This analysis must be based on the system physical model. This sort of analysis is also denominated "failure physics". It is so denominated because failure prevention must occur, many times, at the structural level. In this case, the analysis will be carried out on each component of the system. This usually happens in the preliminary or detailed project stage. Other important parameters to be considered in order to guarantee reliability are: aspects related to material, thermal treatment, form, fatigue and fracture mechanisms, stress levels and use conditions.

4. Methodological application in a mains gas process project

A project system for reliability is presented next. It has been adopted in the preliminary mains gas project, installed in Curitiba and its metropolitan area. It was developed by ALMEIDA (1999).

A mains gas delivery line is a complex product. It must be projected according to international standards, technical norms and specific technical knowledge. According to these premises and to the postulates defined in figure 2, the mains gas project has been classified as part of the military and aerial/spatial market, due to legislation demands and obligatory technical norms. It has also been related to the methods to measure and predict failures, since failure rate data for the principal items are already available. Exponential distribution has been used to calculate reliability.

The mains gas project has been developed for the project process phase in the informational and conceptual stages. In each one of the stages, the set of parameters demanded to approach reliability was highlighted for the whole life cycle.

4.1. Informational design stage

This first stage was divided into four tasks, as shown in table 1. The activities identified with (*) are strongly connected to reliability. Each activity was unfolded in several actions. For instance, the activity identify final clients' criticality (*) in the task analyze market is unfolded in the following actions: register potential consumers, register equipments to be adapted to gas use, study consequences in case gas supply is interrupted, and study alternatives – to be predicted in the project – for raising the system reliability, aiming at high gas availability.

Developing this systematization for each item in table 1, thirty-five client's needs were identified, which generated forty requirements for the product. The relationship between needs and requirements was done through the Quality Function

Deployment Matrix (QFD). Clients' needs and product requirements were divided into: building, fuel, mains, operation, reliability and maintainability. The ordering of product requirements was carried out through the QFD matrix, but, in table 2, only the five initial requirements are presented. It can be noticed that all of them bear strong relation to reliability.

Table 1 – Task definition aiming at the informational project for the mains gas delivery line (ALMEIDA, 1999).

Task	Activity
Plan and identify the task	Define study area; Analyze natural gas offer Define general supply plans; Define life span predicted for the delivery line being considered (*).
Analyze the market	Identify demands; Define project area; Analyze environmental conditions in the defined project area; Identify clients' needs; Identify final clients' criticality (*).
Select ideas	Define various alternative paths; Define parameters to be considered for the mains reliability estimation (*); Study the possibility of closed "meshes" (*).
Elaborate specifications	Work on the needs in order to meet project requirements; Identify existing technical norms, orders and recommendations concerning the subject (*); Request installation previous licenses from qualified organs. (*) parameters linked to reliability

4.2. Conceptual design stage

The general concept of a mains gas project is already known. The norm NBR 12712 (1993) regulates the fuel gas mains project. Figure 3 shows the mains gas diagram with the main systems and components recommended by the norm. The mains gas project, therefore, followed recommendations of the norm NBR 12712. Thus, the mains gas is situated between the gas supply unit and the measurement and pressure regulation stations (EMPR) or the consumer's meter.

Table 2 – Project specifications for the main product requirements (ALMEIDA, 1999).

Product requirements	Specification for the project
1) Replacement of other energy sources by gas	Mains gas project aiming at reaching as high a number of consumers as possible.
2) Demand qualified personnel for building	Elaborate the bid public notice for hiring the delivery line building, demanding exclusive effective participation of personnel with specialized technical qualification.
3) Adopt normalized and/or standardized valves/equipment	Predict, in the project, the exclusive use of normalized and/ or standardized components/ accessories.
4) Predict other supply sources	Develop studies aiming at other possible sources of supply, besides Brazil-Bolivia Gas Pipeline.
5) Adequate filter systems	Project ERPs e EMRPs with filters of capacity compatible with the characteristics of the considered gas.

From the conceptual point of view, the mains could be closed, open, or contain independent chains, having more than one supply entry. The concept presented in picture 4 was opted for due to potential clients, initial investment and expansion possibilities. The installation of this concept within the metropolitan space of Curitiba demanded procedures which were conducted in the form of tasks and activities. Table 3 presents the tasks and their corresponding activities performed. The items highlighted with (*) are directly linked to the mains reliability.

It must be highlighted that, from the viewpoint of some systems components, the activities listed in Table 3 should be carried out in the preliminary design stage. However, some of these activities are being carried out at the level of the conceptual project because, depending on the mains reliability, modifications in the concept initially selected will be demanded.

Each developed activity demands a series of actions. For instance: the failure rate of the principal components and systems to be used in the mains project was unknown. Research was carried out among manufacturers, suppliers, con-

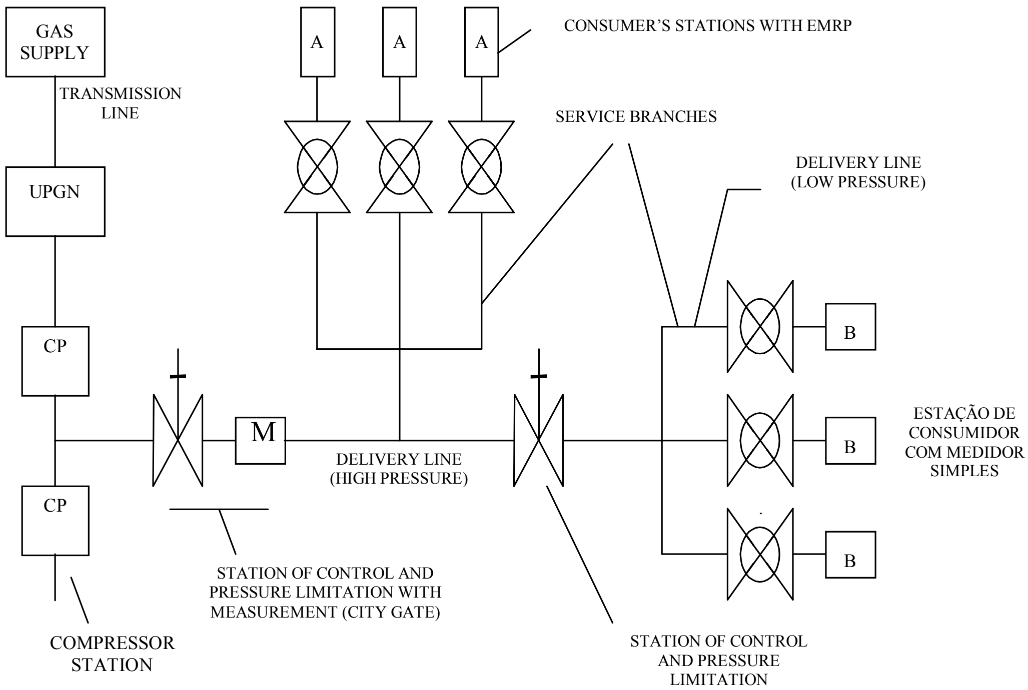


Figure 3 – Diagram illustrating a mains gas transport and distribution system (ALMEIDA, 1999, NBR 12712 –1993).

Table 3 – Task definition aiming at the Conceptual Project of a mains gas delivery line (ALMEIDA, 1999).

Task	Activity
Identify essential problems	Define the sort of project parameter to be adopted; Execute an urban planning; Define project pressures; Identify gas chemical variables; Analyze registers of accidents involving mains gas, as well as their respective causes (*); Analyze registers of failures in mains gas delivery lines (*); Define clearly the most critical items in a mains gas delivery line, as regards possible failures (*).
Establish analysis structures	Classify risk areas; Study testing possibilities for intermediary block valves (*); Identify use and operation conditions to be discarded or regarded as external to the project (*); Divide alternative lines in segments.
Combine and materialize in conception variables	Execute the tubing pre-dimensioning; Identify accessories (valves, meters, filters, etc.) failure rate (*); Identify possible failures in these accessories (*); Consider simple and double EMRPs possibilities (*); Construct mathematical models for calculating EMRPs reliability (*); Construct mathematical models for calculating ERPs reliability (*); Identify procedures in order to detect possible failures (*); Analyze safety systems projects.
Evaluate according technical end economical criteria	Execute studies of segments technical and economical viability; Study the possibility of using new material and equipments as well as their technical and economical viability (*); Verify possible reliability parameters in supply contracts (*). (*) parameters linked to reliability

Table 4 – failure rates of three of the items in the mains gas delivery line (ALMEIDA, 1999).

Component or accessory	Taxa de falhas (l) x10-4/h	Application
Sphere valve	0,1157	ERP/EMRP/Launching Device/Vessels/ Block Valve (line)
Filter type Y	0,7716	ERP/EMRP
Automatic block valve - XV	0,2315	ERP/EMRP

sumers and support agents of similar components used in mains of the petrol sector. In table 4, the failure rates of three of the items which constitute the mains are presented.

In a project like this it is meaningful to consider, besides failure rate, the failure degree of criticality (Ce). In this project, the proposition adapted from Akao (1996) was adopted:

$$C_e = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \qquad 1.\ 8$$

where: F1 – value of the influence caused by failure;

F2 – degree of influence on the system; F3 – frequency of failure occurrence;

F4 – difficulty in preventing failure. Each one of the factors was subdivided into three graduations, representing strong, medium and weak participation in the failure criticality. A failure mode and effect analysis (FMEA) of the mains constitutive items was carried out, as shown in table 5. The failure mode criticality degree is represented in table 6. The determination was a function of the failure mode itself, from the failure effect on the mains gas, and from the cause analysis.

These procedures aim at guaranteeing reliability using the concept of failure accommodating methods, figure 2.

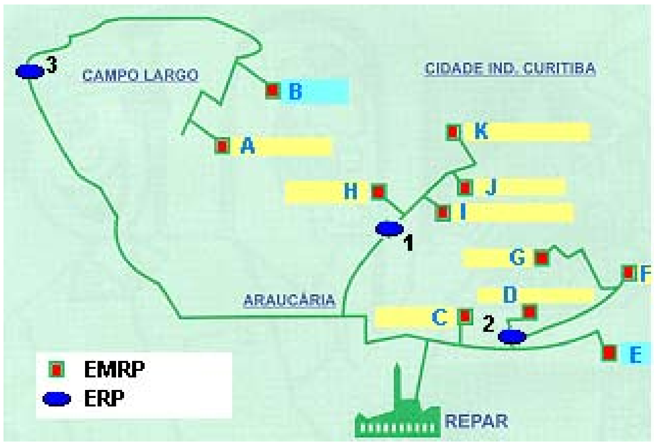
In order to analyze results presented in table 6, the following value scale was adopted: $Ce \geq 10$ – accentuated criticality (immediate measures), $3 < Ce < 10$ – normal criticality (mid-term measures), and $Ce \leq 3$ – acceptable criticality (future measures).

The first stage of the mains gas project was developed to serve eleven industrial consumers, spread around the metropolitan area of Curitiba. Figure 4 presents the map with the eleven consumers, three pressure reduction stations (ERP), and a gas supply central station, the REPAR – Oil Refinery Presidente Getúlio Vargas, Curitiba, Paraná.

The following question has been raised: what is the mains degree of reliability as for gas supply – for each of the gas supply entry listed in figure 4 – at this stage of the project?

In order to answer this question, reliability was calculated based on the respective reliability and mathematic models. Reliability was calculated by using exponential distribution for each of the consuming entries shown in picture 4. It was considered that the mains was operating 24 hours a day, 30 days a month, during 12 consecutive months.

Figure 4 – Refinery gas delivery line conceptual project, for the metropolitan area of Curitiba, PR – COMPAGÁS, for reliability analysis.



The result of reliability estimation, regarding gas shortages for each consumer, is shown in table 7. The first column in table 7 shows the gas consumption entries shown in figure 4. Three estimations were carried out: the first one, shown in the second column, presents the reliability estimation for each consumer – admitting that, in 12 months of nonstop activity, no preventive support must be carried out; the second one, in the third column, presents the reliability value for each point – also with no preventive support, but implementing an active redundancy for the EMRP, that is, double EMRP; and the third one, in the fourth column, shows reliability values considering preventive support in the filter Y, every six months, and in the purgers, every 12 months.

Without preventive support Without preventive support and double EMRPs Preventive support of filter Y every 6 months and purgadores every 12 months

Table 5 – Failure modes and effects analysis of three items in the mains gas delivery line (ALMEIDA, 1999).

Component or accessory	Failure mode	Effect in the system	Cause
Block sphere valve	1) Stuck lever. 2) Not opening after shutting.	1) Impossibility of blocking a given segment in emergency situations. 2) Impossibility of re-establishing flow in a given segment.	1) Working in semi-open position or wear/dirt problems. 2) Too high a pressure differential.
Automatic block valve - XV - EMRP/ERP	1) Shutting out the "set". 2) Non-working with pressure variation 3) Uncalibration in the pilot valve 4) Inadequate shutting.	1) Pressure reduction downstream. 2) PSV irregular operation with possible damage caused by overpressure. 3) Shutting out the "set". 4) Gas block in the line.	1) Uncalibration in the pilot valve. 2) Excessive dirt. 3) Line vibration. 4) PCV insufficient operation.
Filter type Y – Separator	1) Clogging.	1) Clogging purger.	1) Dirt in the filter or saturation of separator.

Table 6 – Criticality degree calculation for failure mode of the items evaluated in table 5 (ALMEIDA, 1999).

Component or accessory	Failure mode	F1	F2	F3	F4	Ce
Sphere valve	1) Stuck lever.	3,0	2,0	1,0	1,0	6,0
	2) Lever Leaking.	1,0	0,5	1,0	1,0	0,5
	3) Not opening after shutting.	3,0	1,0	0,5	0,7	1,05
Filter type Y	1) Clogging.	5,0	2,0	1,5	1,0	15,0
Automatic block valve – XV	1) Shutting out the "set".	3,0	0,5	1,5	1,0	2,25
	2) Non-working with pressure variation.	5,0	2,0	1,0	1,0	10,0
	3) Uncalibration in the pilot valve.	3,0	1,0	1,0	1,0	3,0
	4) Inadequate shutting.	1,0	1,0	1,0	0,7	0,7

As a whole, reliability in the period and conditions considered is still low. However, from this estimation, it can be concluded that the redundancy concept in the EMRPs, as well as the establishment of a preventive support program, improves reliability in meaningful ways. These analyses were carried out separately so that the influence of each one of these aspects could be properly considered.

It could be observed that, even at the level of a conceptual project, it is possible to obtain information concerning reliability, maintainability and redundancy levels to be implemented in a project. Other studies must be developed, at the level of components, in order to reach higher degree of precision regarding failure rate.

5. Final remarks and conclusions

A product should keep good operational conditions and fulfill its function throughout its life cycle. In order to satisfy these demands, it is necessary to measure the mains performance according to those structures presented in the definition of reliability. The mathematical model, in the form of Weibull distribution, cannot be used due to the fact that the failure register – for the mains constitutive items – is still not available. However, once the mains are operating and the failure register is available, several estimations can be carried out.

The adopted process allowed for the systematization of project agents' actions. It could be concluded that reliability requirements, as they were treated through the informational and conceptual project development, will be easily incorporated in other stages of the project, as well as in other phases of the life cycle. This is so because these requirements were highlighted, along the project, in the form of project requirements and quantitative data.

In this work, it was possible to verify that there are several analyses to be implemented for reliability realization in a given project, in a practical and usual way. Some important factors have been highlighted in this work: the influence of a product failure rate, redundancy, support actions planning, and repercussions on the mains reliability in the consumption spot, still in the conceptual project stage. As a result, the project team, managers and technicians were called to consider demanding additional actions in order to improve the mains reliability, before moving towards the installation stage.

6. References

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Table 7 – Reliability Estimation for each consumption point of the refinery gas mains defined in figure 4.

	Without preventive support	Without preventive support and double EMRPs	Preventive support of filter Y every 6 months and purgadores every 12 months
Analysis points fig. 4	12 months	12 months	12 months
Point A	0,489450	0,660753	0,639278
Point B	0,660750	0,660753	0,833442
Point C	0,714810	0,964984	0,752509
Point D	0,489450	0,660753	0,639278
Point E	0,964980	0,964984	0,981063
Point F	0,489450	0,660753	0,639278
Point G	0,489450	0,660753	0,639278
Point H	0,489450	0,660753	0,639278
Point I	0,489450	0,660753	0,639278
Point J	0,489450	0,660753	0,639278
Point K	0,489450	0,660753	0,639278
Points 1, 2, 3	0,684730	0,684729	0,849529

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