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OPTIMIZED PLANNING AND SCHEDULING OF PRESSURE EQUIPMENT INSPECTIONS AT COMAH ESTABLISHMENTS.

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Abstract. In a process establishment, where the legislation on the control of major accidents hazard (COMAH) is enforced, the operator's duties include the implementation of a Safety Management System, which addresses all the procedures significant for safety. A critical issue of the SMS is the planning and the scheduling of mechanical integrity inspections on pressure equipment. This is due to high number of components – including pipes, unfired and fired vessels, pumps and valves, – which could require different technical and organization procedures for testing or inspection. Usually, mechanical integrity inspections may request higher resource use than other safety related activities. The paper presents a model for inspection planning and scheduling, in order to integrate safety issues with other technical and economical issues.

Keywords: Inspection Optimization, Mechanical Integrity, Safety Management System, Major Accident Hazard

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1. Introduction

In a process establishment, where the legislation on the control of major accidents hazard (COMAH) is enforced, the operator's duties include the implementation of a Safety Management System, which addresses all the procedures being significant for safety. A critical issue of the SMS is the planning and the scheduling of mechanical integrity inspections on pressure equipment. This is due to high number of components – including pipes, unfired and fired vessels, pumps and valves, – which could require different technical and organization procedures for testing or inspection. The inspection planning activity in complex plants should integrate safety issues with organizational and economical issues aiming to avoid both unacceptable risks and higher operational costs.

1.1 A model for inspection planning

The paper is aimed to develop a model for inspection planning and scheduling, in order to integrate safety issues with other technical and economical issues. Several issues contribute to increase problem complexity [4]. A few issues are briefly discussed here.

In the European Union the duty holder has to comply with both the legislation on the control of the major accident hazard (the "Seveso" Directives) and the legislation on pressure equipment (the PED Directive). In the framework of PED legislation in many European countries, including Italy, also maximum inspection intervals are ruled. For that reason the optimization should take into account the requirements of the legislation, as well the decision of regulators. The model should take into account critical items, as required by the "Seveso" legislation. These should be controlled more strictly, to prevent major accidents. The model should take into account the different types of inspections that have to be applied to the equipment. Inspections compatible with the plant in exercise have to be discriminated from inspections that have to be done during shutdown time. Visual inspections have to be discriminated from instrumented test.

Function tests have to be discriminated from integrity tests. Controls made by external bodies have to be discriminated from inspections made by internal personnel.
The inspections have a direct cost; but the indirect costs may much higher, if plant shutdown is required. A heuristic approach is proposed here, it aims to “optimize” inspection scheduling and planning activities in Seveso installations. In actual operation, programmed inspection may be cancelled or skipped and the actual program implementation has to be carefully monitored and the inspection schedule has to be updated consequently.

2. Main issues in inspection planning

The risk-based inspection (RBI) and maintenance strategy has been developed by American Society of Mechanical Engineers [1] and improved by American Petroleum Institute [2].

2.1 RBI basic concepts

RBI method prioritizes inspection planning by calculating the risk value, and then it effectively implements an inspection programme [7] [5]. Additionally, RBI reallocates the inspection and maintenance resources to high-risk items while paying appropriate attention to the low-risk items as well. Knowledge and experiences of chemical processes, metallurgy, corrosion and damage mechanism, accidental release modeling, fire prevention and maintenance techniques are key factor for an efficient RBI implementation. RBI takes considerable resources to develop, implement and maintain; moreover, even if a software-based RBI may be applied, the user must be familiar with the basis of the risk models, damage mechanisms technical modules, etc. [3]. Also a complete and up-to-date hazard identification analysis is essential for inspection prioritization. For these reasons, an effective RBI implementation, according to API 580 Recommended Practice [2] implies personnel resources, a strong internal organization and a high budget. Furthermore, risk issues prevail over all other needs, including maintenance or availability, which could be important for inspection programming. Consequently the API or ASME RBI method is suitable for industries featuring a high hazard levels and profuse resources. RBI has been indeed applied in the most refineries [5], in many pipelines [6] and just in a few chemical plants [8] and power–generating stations [9].

2.2 The Mechanical Integrity Inspections and Control of Major Accidents Hazard

As inspections on pressure equipment have been considered essential for safety, they have been regulated for many decades, in all European Countries. The matter has been unified since 1997 by the PED Directive (European Council Directive 97/23/EC). It classifies equipment according to size and operational conditions - “PxV” parameter for vessels and “PxD” parameter for pipelines - and fluid – hazardous or not hazardous.
The Italian legislation defines a specific procedure for the inspections of pressure vessels: it defines maximum inspection intervals for each type of equipment, according to the PED categories [10]. Extended intervals may be authorized, as exception, by the regulators, only if the owner is able to demonstrate that adequate inspection programming methods, such as API 580, have been actually applied in the establishments.
The PED Directive does not take into account whether the equipment is inside a Seveso facilities or not. Anyway some indirect interaction may be found, as the regulators are in duty of performing yearly inspections, which are aimed to verify the adequateness of measurestaken by the operators to prevent accidents, including the management of inspections on pressure equipment.
Recently, a simplified hazard based method, named PELM (Process Plant Equipment Lifetime Management), has been proposed to manage mechanical integrity inspections at hazardous establishments and reconcile the duties coming from Seveso and PED legislations [4]. The model is based on the classification of each component or unit according to Mond index, which is required by the Italian legislation. In detail, an incremental factor - depending on how inspection plans have been developed - could affect the inspection frequency fixed by legislation. The model provide an efficient tool for applying a sort of simplified “risk based” or better “hazard based" inspection in different operational context. This method supports also establishment duty holders, during the visits carried out by regulators, according to Seveso Directive article18.
The integration of PELM with organizational and technical analysis has improved results obtained by the model.

3 **A heuristic model for inspection scheduling and planning**

The main objective of the proposed approach is "optimizing" the inspection plan in industrial installations. The model is based on equipment component prioritization: it considers not only risk influence according to RBI approach but it integrates economical and organizational evaluations. The model does not optimize inspection planning intervals, which represents a model parameter not a variable like in a maintenance model.

Several issues contribute to increase problem complexity:

- For specific types of equipment (e.g pressure equipment) minimum inspection intervals have been defined by legislation. That is maintenance interval optimization models could not be applied.
- Critical items have been highlight in safety reports. These should be controlled more strictly, to prevent major accidents. These requires a priorization – to be managed effectively.
- Different types of inspection activities could be applied to different type of equipment. They could be discriminated both by technical type (e.g. integrity versus funcyionality, non-distruttive versus distruttive controls) and by organizational type (requiring or not a plant shutdown).

3.1 Applying the heuristic method

The proposed model considers all issues described above. Model inputs are described below:

- a list of equipments (APPj with j=1-M) belongs to plant units (Ui with i=1- N) for each installation. This data defines all items which has to be inspected according to their priorization;
- for each j-th equipment (APPj) belongs to the i-th plant Unit (Ui) has to be evaluated the inspection type and its average length (defined by Durata (APPj) parameter). This allows to schedule effectively each inspection activities on each equipment;
- the estimated lenght defined both in hour/day and in day/month defined by ISPEZIONE K parameter. This represents the overall availability estimated for each period for inspection campaign activities.

This parameter does not represent a strictly bound for the model: as it'll show as follows the heuristic procedure verify this bound, the level parameter could be modified if necessary.

The model proposed in this study is a heuristic approach which tries to "optimize" inspection scheduling and planning activities in complex installations. The heuristic procedure is based on priority index (PI) evaluated for each items (i.e a plant equipment).

Main phases are described below:
Phase 1: IP evalution for each item: the Priority Index (PI) has to be evaluated according to technical, economical and organizational evaluations. The IP scoring allows to highlight items which requires priority in inspection planning activity.
The authors propose an IP calculation based on the sum of four factors:

$$PI = LFUN + LFG + LCOST + LRES \quad (1)$$

where:

- *LTG is a discrete variable, which allows to estimate consequences due to item failures. The variable is described in detail in Table 1.*
- *LFG is a discrete variable, which allows to evalute quantitative failure consequences. The variable is decribed in detail in Table 2.*
- *LCOST is a discrete variable, which allows to insert economical estimation of such an equipment. It contributes to evaluate economical value of an item according to its investiment and management costs. More details are reported in Table 3;*
- *LRES is a discrete variable, which allows to evaluate item lifetimes.*

Moreover, it varies according to maintenance strategy applied in the plant.
At first, authors propose five main classes, according to Khan e Haddara (2003) - see Table 1- which aims to estimate LFUN parameter level. Two main options has been proposed for each calss in LFUN evaluation.

Table 1: L_{FUN} parameter levels proposed

Class	Description
1	Relevant for overall system operativity
	A failure could determine a system shutdown
2	Necessary for an efficient system operativity
	A failure could determine unexpected consequences
3	Required for efficient system operativity
	A single failure could determine a reduction in technical performances; it may determine a failure in the overall system
4	Unnecessary for an efficient system operativity
	A failure could not affect immediately technical performances; a prolonged failure may contribute to system fault
5	Unnecessary for a correct system operativty
	A failure does not affect sytem's performances

The L_{TG} parameter may contribute to estimate directly how a single failure contribute to overall plant performances.
In Table 2, 3 and 4 are described L_{FG}, L_{COST}, L_{RES} parameter quantification respectively.

Table 2: L_{FG} parameter levels proposed

Class	Description
1	Very high failure rate compared to reference period length
2	High failure rate compared to reference period length
3	Medium failure rate compared to reference period length
4	Low failure rate compared to reference period length
5	Very low failure rate compared to reference period length

The L_{FG} parameter quantifies how failure rates may influence system functioning. Together with the L_{FUN} evaluation, it contributes to estimate how an equipment affect overall system functionality.

Table 3: L_{COST} parameter levels proposed

Class	Description
1	The economical equiment value is more than 100.000 euro
	A system shut-down may cause an overall of the process
2	The economical equiment value is between 100.000 euro and 50.000 euro
	A system shut-down may cause a partial but relavant stop of the process flow
3	The economical equiment value is between 50.000 euro and 25.000 euro
	A system shut-down may cause a partial but not relavant stop of the process flow
4	The economical equiment value is between 25.000 euro and 10.000 euro
	A system shut-down may cause a reduction of the process flow
5	The economical equiment value is between 10.000 euro and 5.000 euro
	A system shut-down may not cause a stop of the process flow

The evaluation of L_{RES} parameter introduces a relationship between economical and technical evaluations about an equipment. So the aim is to introduce in planning inspection campaigns an evaluation of economical facilities value, directly, by investiment cost and indirectly, by reduced plant functioning.

Table 4: L_{RES} parameter levels proposed

Class	Description
1	Scarce residual equipment lifetime and inspections never carried out
	Proximity to obbligatory deadline inspection
2	Moderate residual equipment lifetime
	Last inspection has been carried out more than half of residual lifetime
3	High residual equipment lifetime
	Last inspection has been carried out more than two half of residual lifetime
4	Installation date not more than one year
	Inspection has been carried out in previuos planned campaign
5	The equipment has been installed exnovo after the last inspection
	The inspection has been planned for the next campaign

The L_{RES} parameter may contribute significantly to inspection scheduling and planning: as described in paragraph 2.2: effective inspection campaigns developed according to SMS could contribute to avoid obligatory inspection verify. The phase stops when PIs have been evaluated for all M componets of the N units. Now, the second phase could start.

Phase 2: Heuristic procedure for optimize inspection planning activities. Input of this second phase is a list of all equipments which has to be inspected in the installation, ordered by PI level. The heuristic procedure starts from the first equipment in the list (APPj $\in U_i$), such as the equipment characterized by the highest PI values. The procedure aims to "optimize" total inspection costs by assigning all equipments belong to the same plant unit (U_i) to the same inspection campaign (defined by the k-th ISPEZIONE). So, shut-down and organizational costs regarding an inspection may be reduced. Starting form APPj, the procedure verify the equation (2).

$$\text{Durata (APPj)} \leq \text{ISPEZIONE}_K \quad (2)$$

If the length of the inspection on j-th equipment (Durata (APPj)) is minor or equal than k-th inspection campaign length (ISPEZIONE_k), the equipment is assigned to the the current inspection campaign. Now, a recalculation of available inspection lenght has been carried out; the residual length avaible for inspection scheduling is defined by equation (3):

$$\text{ISPEZIONE}^*_K = \text{ISPEZIONE}_K - \text{Durata (APPj)} \quad (3)$$

As described in paragraph 3.1, this parameter could be modified if necessary. The inspection length varies depending of the j-th APP and it is defined as input.

If equation (2) is not verified, it will be evaluated the next inspection campaign available (ISPEZIONE_{k+1}) defined at first as input. Iterative procedure continue until all equipment belonging to the i-th unit (M equipments) has been assigned to an inspection campaign.

Now, the procedure evalutes the equipment subsequent in the list according to PI level.

The procedure stops when all equipment of all plant unit (N units) have been scheduled for inspection. The proposed approach aims to determine the optimum combination of equipment inspection methods, technical - such as safety and operativity issues - and organizational performances by an heuristic approach.

4. The Software Prototype

A software prototype has been developed according to the proposed heuristic approach. An integrated decision support system has been developed: PELM, the simplified hazard based model described in §3, has been integrated with a platform called IPSE (Inspection Planning in Seveso Establishments) which manages organizational activities regarding inspection planning and scheduling. IPSE platform has been developed according to Web Client-Server N-Tier techonology. The IPSE architecture is modular and flexible; this allows to supply an efficient tool for managing high information quantity typical of inspection planning activities in complex systems.

Conclusions

The developed system has two items a risk ranking modeller and a scheduling support system. The risk ranking modeller manages basic issues, including critical item identification, mandatory frequencies calculation. The scheduler support decision about planning and scheduling. For each item of the equipment, the scheduler receives basic information from the risk modeller and plans month by month the inspections, according to risk ranking, inspection costs, regulatory and organizational bonds. Furthermore it re-schedules day by day the inspections, according the actual plant operation. Records of performed inspections are managed by the scheduler. They may be processed to send back information to the risk modeller. These items of information may be significant for improve the risk ranking and to update, consequently, inspection priorities. Software has been developed according to Web Client-Server architecture.
Furthermore software could be used to demonstrate to the competent authorities, which have to monitor the plant in the framework of the Seveso legislation, that the mechanical integrity of the equipment, as actually controlled, is adequate to ensure safer operations.

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