UNIVERSITY OF PETROȘANI
DOCTORAL SCHOOL
FIELD: MINES, OIL AND GAS

SUMMARY
THESIS

RESEARCH ON INCREASING THE QUALITY OF SOME METALLIC STRUCTURES AS A COMPONENT OF ROTOR EXCAVATORS

Coordinator,
Professor PhD. Eng. Radu Sorin-Mihai

Student,
Eng. Oltean Ilie-Lucian

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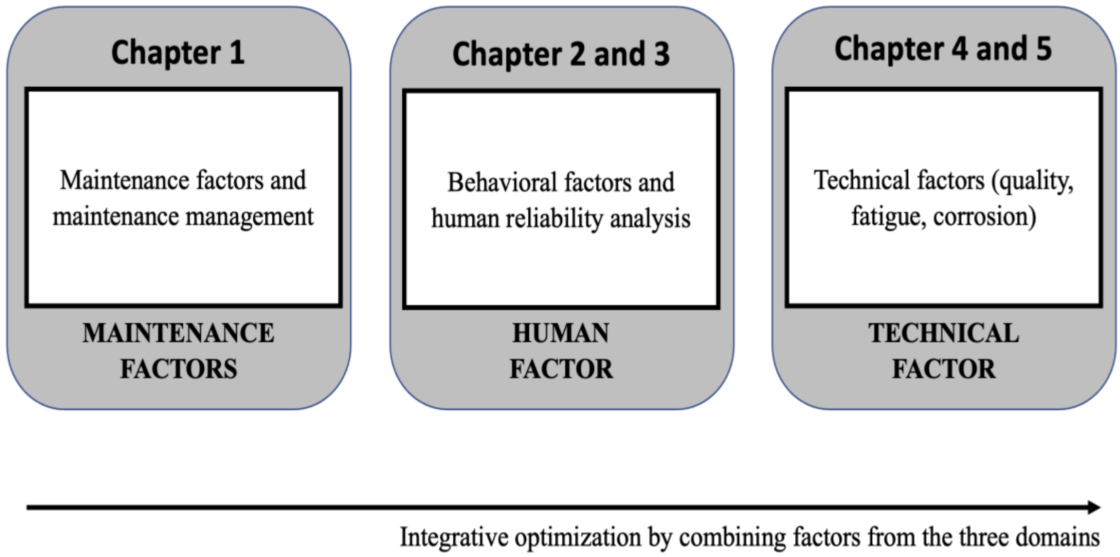
CONTENT

SUMMARY

The theoretical structure of this paper takes as its starting point that maintenance must be conceptualized as a complex field, and this complexity is reflected in any modeling of possible optimizations. If maintenance is conceptualized as consisting of and information about three distinct domains, including (a) maintenance, (b) the human factor, and (c) the technical factor (see the conceptual model below), maintenance optimization can be achieved by an accumulation of discrete theorizing and interventions from each field.

Conceptual model and corresponding chapter development



In simplified terms, if the above three domains are visualized as discrete vectors, presented in one-dimension form (respectively x_i, y_i, and z_i), the maintenance optimization (Π), should result from combining the elements of the three domains (x, y, z). It should be noted that an approach based only on the first domain, that of maintenance management (x), would be one-dimensional and would only deal with aspects of this domain. Likewise, an approach focused exclusively on the human factor (y) would ignore the other two components. Finally, an approach focusing part (z) would not consider the other two factors, with their focus on maintenance management and the behavior of employees responsible for maintenance. Specifically, any one-dimensional approach – focused exclusively on technical aspects, for example – would only target a single factor (or domain) and its optimization (in this case, the vector vectorul z_i), in which case the indices of the other two factors would be set to zero (x_i, y_i, with i = 0), their domains not being discussed and not used for optimization. A more complex, interdisciplinary approach to maintenance – as proposed in this paper – must use a multitude of factors and consider their combination, depending on the specific situation and firm`s resources.

The modes of conceptualization and modeling of the factors in the conceptual scheme above are briefly presented, summarizing the issues and theses of the corresponding chapters, as follows. **Chapter 1** traces the general direction of theorizing the concept of *maintenance* which, in this work, will focus on both an approach directed towards the behavioral aspects (the human factor, **Chapters 2** and **3**) and one directed towards the mechanical aspects (the technical factor, **Chapters 4** and **5**).

Chapter 1 focuses on (a) an introduction to the concept of maintenance, (b) a discussion of existing definitions, and (c) a description of models used in the literature. The research method used is (i) search for articles in the specialized literature (over 100 articles initially considered), (ii) selection of the relevant ones (around 50 papers), and (iii) critical analysis of the content. This latter analysis, which goes beyond the simple listing and enumeration of definitions, brings with it a necessary synthesis and critique, culminating in a discussion of how the complex concept of maintenance can be conceptually unraveled and used concretely. An important conclusion drawn from this integrative effort is the need to situate the concept of maintenance in a (a) broadened conceptual framework, (b) appropriate to the specific research theme, and (c) empirically validate the resulting theories and models using methods that will be discussed in the following chapters. More specifically, an adequate evaluation of the maintenance concept and related performance must be directed not only to the technical factor (see **Chapters 4** and **5**) but also to the behavioral factor (see **Chapters 2** and **3**).

Chapter 2 brings into discussion a first behavioral aspect, complementary to the technical one through a discussion of the various perspectives used to understand the behavior of the human factor associated with maintenance problems. The chapter presents the theoretical approaches employed to understand behavior, using a multidisciplinary approach. Thus, theories of behavior as they appear in three different disciplines are presented, (a) theories from the field of industrial psychology (subchapter 2.3), (b) theories from the field of organizational behavior (subchapter 2.4), and (c) theories from the field of analysis human reliability (subchapter 2.5). As for the previous chapter, the method used is search, selection and synthesis, resulting in the understanding of (i) a specific literature, (ii) its evolution and (3) its positive and negative aspects. The multidisciplinary process used brings with it the advantage of conceptualizing maintenance-related behaviors from multiple perspectives. For example, while in the field (1) of industrial psychology the focus falls on how to conceive and optimize the employee’s competence, in the field of (2) organizational behavior efforts are directed towards a more complete conceptualization of performance, including extra-role performance. Finally, in the domain (3) of human reliability analysis, the models emphasize decision-making aspects. As in the previous chapter, beyond listing theories, the goal is to evaluate them (and then use them, their use being discussed in **Chapter 3**).

To facilitate this evaluation, a central role in this chapter is played by the criteria presented in Table 2.1, where (i) a classification of the principles of theoretical formalization and modeling (integrated based on the specialized literature) is proposed and (ii) a selection of those relevant to this work (see the second column, titled “Used in the present work” in Table 2.1) is then performed. These criteria are worth discussing in more detail because they may inform other maintenance research efforts. As the objective of maintenance research is its optimization, a simplified modeling considers that ensuring reliability and quality (y), depends on a causal vector x. Both cause and effect can be modeled in a more complex manner, as vectors ($X_i \rightarrow Y_i$) or even as entities with a multidimensional quality.

The literature (e.g., Mohaghegh și Mosleh, 2009) has considered several principles to be used when performing such optimization. In the conceptual diagram below, the principles that can be used for optimization as discussed in the literature are presented in the left-hand column; in the right column, only the principles relevant to this work are retained. Only the relevant aspects have been retained, considering that the objective of this paper is focused on a specific problem and machine.

Classification of theoretical formalization and modeling principles

Categories	Principles	Used in the present work
I. Designation and definition of objectives	(A) Entity ___ unknown but showing interest	✓
	(B) Objective and multidimensional performance	✓
II. Modeling	(C) Safety and deviation from the norm	
	(D) Multi-level framing	
	(E) The level of depth and detail regarding causality	
	(F) The degree of generality of the model	✓
III. Fundamental elements	(G) The fundamental unit of analysis	✓
	(H) Level and nature of factors	✓
	(I) Selection of factors	
	(J) Connections between level, nature and structure	
	(K) Dynamic features	
IV. Technically	(L) Measurement techniques	✓
	(M) Modeling techniques	✓

In the specialized literature, the objectives (category I, principles A and B, see above) are generally related to the research topic. In the model presented in the literature, the objectives are to ensure safety and performance in socio-technical systems. These objectives are similar to those of the present work, where the focus is on reliability and quality, making these first two principles applicable. It is therefore necessary to model both an unknown but important entity (principle A), applied in this case to reliability, and performance (principle B) which must be of a multidimensional type (to consider both technical aspects, as well as others that consider organizational and management aspects).

The degree of generality (principle F) of the model is important, given the tension between a way of modeling behaviors viewed in their (a) general aspects, in contrast to (b) a type of modeling focused on a specific behavior. For example, this contrast is discussed in section 2.3, where such a tension and differentiation between a general ability (employee intelligence) and a set of specific abilities (competencies) is presented, an idea that underpins the entire theory of competency models.

The fundamental unit of analysis (G) and the nature of the factors (H) consider the behaviors of employees responsible for maintenance, behaviors problematized at a conceptual level. The last two principles relate to measurement (principle L) and modeling (principle M). The specialized literature recommends "a multidimensional coverage of measurement bases (what to measure) and measurement methods (how to measure)" (Mohaghegh and Mosleh, 2009, p. 1147). The use of hybrid methods is recommended for both (a) measurement bases, combining direct (e.g., accident frequency) and indirect (perception and application of safety practices) measurement, and (b) measurement methods, combining a mode of objective measurement (audit, collection of observations), with subjective measurement (questionnaire, interview).

The chapter continues with a presentation of how to conceptualize the behavior of employees responsible for maintenance. Specific conceptualizations are based on (a) industrial psychology, (b) organizational behavior, and (c) reliability analysis. The content of the respective theories is presented, followed, at the end of each section, by an assessment of how the respective theory is aligned with the principles stated above (see points A-M in the diagram above, entitled *Classification of the principles of theoretical formalization and modeling*). These criteria are used to evaluate the theories previously presented in the three fields of (1) industrial psychology, (2) organizational behavior, and (3) human reliability analysis, resulting – respectively – in three tables and corresponding ratings (Table 2.3, 2.4 and 2.5). This integrative effort, useful to those who study the behavior of employees responsible for maintenance, is supplemented in the next chapter with a concrete and practical part.

Chapter 3 continues in a practical and empirical way the application of the theories presented in the previous chapter. The focus falls not only on a problematization of behavioral aspects but also on the presentation of possible solutions, with special attention paid to the ways in which these solutions are selected. Thus, a first focal point of this chapter is Table 3.1, where the advantages and disadvantages of modeling behavior using a (a) general or (b) specific theoretical framework are briefly discussed. It is also worth noting here the effort to connect the present investigation with a wider, multidisciplinary conceptual space, using in this case fundamental notions from the field of logic (applied to concepts). Thus, the general mode of conceptualization (of behavior) is associated with a presentation of the intensional or connotative concept (the common properties of a category) and the specific mode of conceptualization associated with an extensional or denotative part (the specific properties of the objects in that category). The remaining sections discuss possible ways of resolving the general-specific tension in theories from (a) industrial psychology, (b) organizational behavior, and (c) human reliability analysis.

A first approach (1) aims at how a solution can be achieved at a level of the choice of the research method. For example, in organizational behavior, the general-specific tension at the conceptual level informs the research methods used (Figure 3.4) and they maintain this tension at the level of the research methods used, being discussed in Table 3.6 (the general aspects corresponding to the methods using a questionnaire on a representative sample and specific aspects corresponding to research studies in a specific work environment).

A second approach (2) aims at how the solution can be achieved by implementing concrete ways of research and using related (data collection) tools. Thus, the following sections (3.3, 3.4 and 3.5) present suggestions for data collection and analysis, by using (a) the critical incident method (in industrial psychology), by using (b) questionnaire-based techniques and workplace observations (organizational behavior), or by employing (c) techniques based on factor or cluster analysis (human reliability analysis). For greater clarity, examples of tools that can be used for data collection using expert ratings (Table 3.14), observation (Table 3.15), and self-assessment (Table 3.16) are provided.

Completing the first chapter of an integrative type, the following two chapters (2 and 3) problematize maintenance-related behaviors and show that their complex nature requires (i) a clarification of the theories used in their conceptualization, (ii) an explicit presentation of the methodology used and (c) an empirical counterpart focused on data collection and analysis. The following chapters (4 and 5) focus on technical issues as follows.

Chapter 4 (*the technical factor*) represents the theories and tests related to the technical aspects. Next, as a result of the experimental study on the details, the ways in which the degradations originate and develop in certain overloaded areas were also presented.

The different types of welded plates were carried out through the theoretical study and then analyzed using the finite element method in the weld area so that it was determined how the stresses in the weld arise (MAB, MA, ZIT). One final conclusions regarding chapter 4 is that the need to find solutions to extend the life of these machines was imposed by researching the lower part of the quarry machines. For purely objective reasons, the work looked at the redesign and repair of machinery, finding out the degree of aging and searching for the best and most suitable methods and technological processes of repair. With the help of electro-resistive tensometry during the repair when the track strut was modernized, the degree of influence of wear on the way of stressing the metal structure was established and the efforts that act on the lower part of the metal construction, which works for more than 2- 3 decades. During the dimensional control of the old St 52.3 material, degradations of up to 18% of the thickness of the investigated areas were found.

The degree of degradation can be appreciated by knowing (a) the degree of external oxidation in the area of the joints, (b) the microstructure and macrostructure in the characteristic areas for welding, (c) the formation in the area where oxides do not penetrate the corner welds, etc. and whose fragility leads to a shortening of the life of the welded assembly. The comparison of the old (30 years) welds with the new ones made on new steel, when joining with the old steel (German steel) where no defects appear, indicates that carefully made welds have a good behavior of the mechanical characteristics in the destructive tests. At the same time, the pulsating test brings out superior characteristics for the new steel compared to the old steel.

Therefore, without introducing different high thermal regimes in welding and even knowing both welding processes that are applied in the processes, MAG welding has better qualities for voltages of about 25V, welding currents of 210-225A. If the welding is done manually, the negative influence is given by the welding voltage, being reduced below 30V, which leads to a reduced welding quality. On all machines from the surface quarries of the ERC 1300 type excavator, the realization of the rehabilitation process by welding of the lower metal construction was finalized technologically and constructively on the basis of experimental research and their exploitation on the machines with long operation.

Chapter 5 (the technical factor) is also focused on technical aspects. In the following, final conclusions are presented regarding this last chapter of the thesis, being noted that due to the actions of the efforts generated by the cutting organs on the arm of the bucket wheel, the fatigue phenomena could be analyzed and a theoretical study was carried out, thus studying the areas with overloads. By examining the structure of steel, the phenomena at the level of atomic bonds, grains, etc. can be known, even down to the detail aspects of the metal structures in a machine sub-assembly.

The fatigue curves for the metal were, evidently, presented in theory but also for the detail areas (holes for screws, welds, etc.); overall, they help establishing the places where experiments can be carried out consistent with the theme of the thesis. More precisely, it can be established that the fatigue theory in the metallic structure differs from that of the seamless metallic structure, this being possible through the theoretical approach to the study of welds. One of the necessary conclusions is that major differences in the fatigue curves are highlighted following theoretical studies on the knowledge of the behavior of the metallic structure with many welds.

Therefore, for the last two chapters (chapters 4 and 5, focused *on the technical factor*), the general ways and researches for certain determinations of the efforts, of the quality of the welded joints after rehabilitation or the analysis of the degradation state were presented. The manufacturing method of the welded assembly was highlighted both from a technological and constructive point of view. Chapter 5 focused on the analysis and interpretation of the degradation phenomena of the fatigue methods of the materials and the analysis of the load-bearing structure by electrical-resistive tensometry, thus being able to observe the major differences in the fatigue curves and to learn more on the behavior of the metal structure.

FINAL CONCLUSIONS

Chapter 1 (conceptual aspects of maintenance), focused in its initial aspects on a presentation of definitions related to maintenance and a description of existing models, continues in its in-depth aspects with a critical discussion of definitions, models and theories. A final conclusion regarding this chapter and the ways in which the concept of maintenance is defined and theoretically framed is the need for authors examining the concept of maintenance to (a) frame it explicitly in one of the ways of conceptualization presented (including an explicit presentation of the definitions used) and (b) to delimit the modes of analysis which are left in the background). Without such clarification and clarification, the concept of maintenance will be limited to a vague or one-dimensional conceptualization. In parallel, maintenance must be (a) conceptualized dynamically, (b) viewed from various perspectives, (c) conceptualized using as many models as possible appropriate to the technical and behavioral problems encountered, and (d) contrasted with an empirical and practical side which at the same time brings a necessary – and often neglected – validation of the model used, discussed below.

Chapter 2 (behavioral aspects), includes the various perspectives used in modeling behavior and the human factor, including the theoretical approaches used, while Chapter 3 represents a continuation at a practical and applied level of the theories and models presented in Chapter 2. An important conclusion is in the need to include in maintenance analysis works, at a first level, modes of analysis that (a) problematize such behavioral aspects, (b) synthesize related literature, and (c) offer possible solutions by (i) presenting directly usable models (questionnaire example, Table 3.14) as well as broader guidance systems to help researchers interested in modeling and evaluating behaviors (general-specific tension, Table 3.1) and in possible empirical research activities (Figure 3.4).

This validation, which can also be seen as an evaluation of maintenance performance, must be framed not only by the technical factor (see Chapters 4 and 5) but also by the behavioral factor (see Chapters 2 and 3), the latter discussed below. The final conclusions (referring to Chapters 2 and 3) start from and return to the fact that the human factor and related behaviors have a complex nature, which requires (a) an explicit modeling of the theories used in their conceptualization, (b) a clarification of the methodology used (see for example Figure 3.4) and (c) a multidimensional approach to empirical effort (based on observation, questionnaire, etc.).

PERSONAL CONTRIBUTIONS

Personal contributions are detailed below as follows:

- in the first chapter, we theoretically framed the concept of maintenance by presenting the definitions and models related to this concept, as found in the specialized literature. An important contribution is the broadening of the research direction to a conceptualization of maintenance that includes not only (a) technical aspects, but also (b) administrative, (c) managerial and (d) quality optimization ones.

- we emphasized the administrative and managerial aspects, usually not discussed or left in the background in the literature. Thus, we have once again brought to the fore issues related to the evaluation and optimization of maintenance.

- we consulted a wide literature, based on which we proposed a classification of maintenance that must take into account (a) the models used, (b) maintenance techniques and practices, c), scheduling (temporal, spatial, resource-based (human, etc.) of maintenance, (d) measuring (or evaluating) maintenance performance, (e) maintenance operations support systems, and (f) maintenance regulations and maintenance management. It should be noted that this classification brings with it new aspects, expanding previous research work predominantly focused on technical and practical aspects (point "b" above).

- next, using the specialized literature, we briefly presented the content of the above domains and critically evaluated each of the six domains. Thus, we classified the models that frame the concept of maintenance as being based on (a) a Bayesian approach, (b) linear programming techniques, (c) probabilistic, or (d) based on the human factor, and presented an evaluation critical (Section 1.2.2).
- the technical aspects required the consultation of a large number of specialist papers, from which we selected over 50 relevant papers, which informed the classification of these technical aspects (Section 1.2.3). Here too, we have presented a content-wise classification of technical aspects of maintenance into ten domains and briefly discussed their relevance. By broadening the conceptual base (preventive, predictive maintenance, etc.; section 1.2.3) and by presenting it in a systematic manner, we redirected research directions to aspects less common in the literature.
- regarding maintenance performance, we presented a classification (see points a-k in Section 1.2.5) that goes beyond the typical approaches, focused on the economic (budget) and technical (availability, operation, etc.) side. By presenting this classification, we have contributed theoretically (broadening the concept of performance) and practically (interested researchers can use some of these techniques to conceptualize and implement performance).
- in the second chapter, using recent specialized literature, we emphasized the importance of the human factor in the maintenance process (see Figure 2.1, where this factor is presented as being as important as other aspects such as materials, spare parts, and technology) . One of the preliminary contributions is the set of arguments in section 2.1, where we emphasized the need to study the behaviors of employees engaged in the maintenance process.
- a first contribution is that we foregrounded the role of behaviors in maintenance activities, in contrast to works focused on technical aspects.
- the second, more important contribution is focused on the fact that to discern the human factor and model its role in maintenance optimization, an interdisciplinary approach is needed. Thus, in Table 2.1 we presented – based on the literature – the theoretical criteria necessary for the conceptualization of employee behaviors and we argued for the selection of the criteria used in the present paper.
- further, using the aforementioned multidisciplinary approach, we conceptualized employee behavior as it appears in fields and disciplinary specialties such as (a) industrial psychology (section 2.3), organizational behavior (section 2.4), and literature related to human reliability (section 2.5) . And here the contribution is both theoretical and practical (with an emphasis on the practical contribution in Chapter 3, where we presented concrete examples of measuring and evaluating behaviours). Returning to the theoretical contribution, it focuses on the conceptualization – different, depending on the disciplinary field used – of behavior.
- thus, we consulted the specialized literature in the field of industrial psychology, and discussed the concept of competence, with its inherent advantages and disadvantages. An important contribution in this subchapter is the analysis of the criteria necessary to formalize behavior (Table 2.1) applied in the field of industrial psychology, a field in which behavior is qualified as an employee's skill (or his competence). We have analyzed and summarized these aspects in Table 2.3.
- the same modus operandi – with corresponding personal contributions – follows in section 2.4 (in which we discuss theories in the field of organizational behavior) and 2.5 (in which we address theories in the field of human reliability). And here, we consulted a

number significant number of works, the most important contribution being that we have made a synthesis of them and a discussion of the advantages and disadvantages (Table 2.4 for the field of organizational behavior and Table 2.5 for the field of human reliability).

- although useful to researchers interested in the study of maintenance, the theories and models presented above – including in a synthesized way and emphasizing advantages and disadvantages – would be less useful without the practical approach used in Chapter 3, with related contributions, presented as follows.
- chapter 3 continues with a practical application of the theories and models presented in chapter 2. First, we brought these practical aspects to the fore, synthesized the relevant literature, and presented possible solutions. Next, we addressed the issue of evaluating behaviors that, from a technical point of view, can be – at the extremes – either (a) too general or (b) excessively specific. Although Table 3.1 is based on the literature consulted, in the discussions surrounding it we used an interdisciplinary approach and discussed the general-specific tension using, among other things, fundamental notions from logic.
- a contribution found throughout the chapter is a discussion of how employee behavior can be assessed using insights from the areas discussed in the previous chapter. In Table 3.4, for example, we presented a number of best practices for assessing employee skills; likewise, in Figure 3.4, we presented possible solutions derived from the field of organizational behavior. They may be useful to researchers interested in assessing behaviors using the disciplinary and analytical domains mentioned.
- a more concrete level of specificity is reached in sections 3.3, 3.4 and 3.5 where we presented concrete ways of assessing competences, measuring behaviours, and analyzing incidents. Personal contribution is present here in the set of methods that can be replicated or adapted by other researchers (eg questionnaire, Table 3.14) interested in studying maintenance and employee behaviors or interested in synthesizing a large number of quality and maintenance incidents (by factor analysis or by conceptual sectors, Table 3.17).
- a final contribution, based on these first three chapters, is the depth of the study, running vertically from theoretical to practical, and horizontally passing through several disciplines and fields that can inform a study of maintenance behaviors.
- in chapter 4, we carried out technological research regarding the rehabilitation of the metal construction where a) we analyzed from a technological and constructive point of view the way of making the assembly, where from the analysis of the way of behavior in operation it constructively resulted that, the spar assembly, are parts that must be replaced in the repair or rehabilitation process.
- we have described (see Table 4.1) the technological stages for obtaining welded metal structures, namely (a) the first stage of material control, (b) the second stage of preparing the assembly by welding, (c) the third stage of assembly by welding, (d) the stage the fourth post-weld operations and (e) the last stage of final control.
- we have done research on the state of degradation of welded joints that have worked for a long time and on the quality of welded joints after the structure has been modernized (rehabilitated).
- we performed an analysis of welded structures using the finite element method, where we described the stages that are followed in the application of the research through the analysis of this method. At the same time, we presented in Figure 4.17 a geometric (3D) model of the rocker arm where we applied the contour conditions, and on the inner surface of the bushing the forces from the clamping bolt were applied, where after that a static analysis was made which was carried out by discretization and thus the equivalent Von Misses voltages could be observed.

- in chapter 5, we presented the effect of corrosion on the load-bearing structure, we described the main stages of destruction by fatigue processes in the presence of corrosive environment, including (a) the initiation of pinches, (b) the evolution of pinches, (c) the propagation of short cracks and (d)) propagation of long cracks.
- we presented the fatigue resistance evaluation methods, we synthesized and presented the phenomenon of mechanical degradation.
- we have carried out extensive documentation for the procedure of drawing the S-N diagram in mining and depositing machines, where using the equations, we have drawn the Wöhler curve for the node beam in the bucket-carrying arm subassembly of the machine and detailed the diagram in Figure 5.19.
- we have described the analysis method for the load-bearing structure by electrical-resistive tensometry, although any tensometric test must be done based on a test project developed by a specialist in such measurements and which should be in collaboration with the beneficiary of the test.

FUTURE DIRECTIONS OF RESEARCH

From a perspective of the study of maintenance from a conceptual perspective, future research directions result from (a) limitations in approaching the concept of maintenance as it appears in the literature and (b) from a number of specific trends – conceptual and technical – which can only be sketched here. An important aspect is to validate maintenance models (section 1.2.7, especially 1.2.7b) and establish their effectiveness. Only future research can assess – comparatively – how one model (focused, for example, on prevention) is more effective (or not) than another model (focused, for example, on predictive aspects). For such comparisons to be possible, it is preferable for authors studying the concept of maintenance to frame it in a multidimensional perspective.

For chapters 2 and 3 future research directions follow from the contributions presented above. First, any literature has a dynamic character and evolves in new directions, sometimes in a very short time. Any future research therefore requires the use of current techniques for searching and finding new trends (through database searches and an appropriate selection of articles found). More important, however, in the second place, is the understanding of the theoretical foundations on which the literature and its evolution are based. Such an integrative theoretical effort has been made above, for example in Table 2.3, Table 2.4, and Table 2.5 (as well as the related text), where the focus is on the integrative theoretical part. Future research should therefore not neglect such theoretical and synthesis aspects. The fact that there are currently many discussions about artificial intelligence and related automatic processing techniques ("machine learning") does not justify a presentation and use of them detached from the theoretical aspect. Future research will therefore need to theoretically justify such trends and integrate them into conceptual structures.

For chapter 4 as future research directions would be to improve and increase the reliability of the excavator travel system. They can follow section 4.5.2. As described in section 5.1, where different forms of corrosion could be observed, and where the conditions for the appearance of corrosion were the presence of tensile stress and/or the presence of a corrosive agent specific to the working environment, future research can be done to steels by protecting them by applying a protective layer by hot-dip galvanizing and subsequently testing them according to the working environment to see if tensile stresses stimulate corrosion and compressive stresses further inhibit it, as well as to reduce corrosive agents (sustainable development with environmental benefits) on the surface of the metals, thus extending the life of the machine.

For chapter 5, the future research directions could be extended by applying the analysis method (section 5.10) of the load-bearing structure by electrical-resistive tensometry, being able to be extended to the entire structure of the machine, of course for these it is necessary to perform tensometric measurements or according to the areas of the tensometric points determined by MEF (finite element method). Of course, as well as future research directions, the continuation of studies and the type of preventive actions to keep the machines in good working order and to eliminate possible subsequent events can be considered.

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