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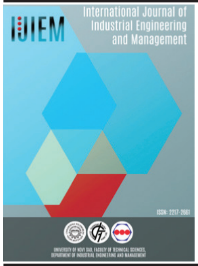

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Review article

Joint optimization of production, maintenance, and quality: A review and research trends

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A B S T R A C T

In the industrial context, the smooth running of production requires the proper functioning of the machines as well as the quality of the products manufactured. In practice, production, maintenance, and quality are often managed separately, despite their close linkage. Therefore, it is essential to jointly manage production, maintenance, and quality strategies to ensure the overall performance of the company. For these reasons, this paper presents a recent and relevant literature review of existing joint maintenance, production, and quality management models. It also discusses how to enhance their applicability in the industry. First, we start with a classification of the selected publications according to different criteria. Second, we provide a detailed analysis of the integration of production, maintenance, and quality control policies studied in the literature. Then, we introduce optimization methods for the integrated models and validation tools for these models. Thirdly, we discuss the findings of the state-of-the-art analysis on the integrated management of production, maintenance, and quality. Finally, we conclude by highlighting the contributions obtained and suggesting future research directions.

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1. Introduction

In real terms, production systems do not consistently generate products of high quality. Furthermore, equipment deterioration can affect the quality of the manufactured products. In this regard, therefore, the focus has gradually shifted to the management of manufacturing system operations, quality control, and maintenance activity planning. On the other hand, an understanding of the dependency between production, maintenance, and quality will open a new path for integrated models. Among the benefits of joint management is cost reduction as well as performance improvement. Nevertheless, integrated models are not generally easy to solve due to their multi-objective nature. Obviously, production, maintenance and quality are three functions with different objectives. In the literature, these three functions are frequently treated separately.

Consequently, and in order to maximize the company's profits, a joint management is necessary. Indeed, several studies have estimated the importance of quality on the joint optimization problem of production and maintenance. Taking into account the gap between research on the joint management of the three functions (production, maintenance and quality) and industry, the objective of this work is to exploit existing models in the literature to understand

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the dependence of production, maintenance and quality, and to discuss and analyze the results found. Indeed, the study of this dependence makes it possible to come as close as possible to the reality of the industrial environment.

In fact, much of the research in this field has appeared in the press in recent years. This indicates a growing interest in integrated models for production, quality, and maintenance. On the other hand, the existing literature review articles deal with the three functions: production, maintenance, and quality two by two. In another way few articles a recent and detailed bibliographical study is made for the problem of the joint management of the production of the maintenance and the quality. According to our research, we found four literature review publications dealing with the same topic during our research interval (from 2005 to 2023).

We begin with the reference review [1], the authors have made a bibliographical study based on 22 references. This study is particularly interested in maintenance optimization techniques and quality control of a production tool based on the measurement of quality indicators. The authors aim to create a new model based on the conclusions drawn from the literature review that carried out. On the other hand, our paper targets a broad category namely students, researchers in this field as well as for our future work. In addition, there is another review of the reference [2]. The aim of the review is to study at the same time the interdependent and integrated models of production planning, scheduling, maintenance, and quality. This review pays particular attention to integrated model cost calculations. Similarly, [3] focuses on cost formulas for production, maintenance, and quality planning models. This review highlights aspects of the production workshop such as flow-shop, open-shop, job-shop, etc. The authors try to approach a real workshop environment, in which multiple machines with multiple components in different manufacturing environments processing multiple products. Finally, the authors of the reference [4] dealt with the concept of integration through transfusion between total quality management (TQM), total productive maintenance (TPM).

Our work stands out from other papers in its rigorous structure and methodical approach. We conducted a comprehensive literature review, covering the period from 2005 to 2023, to address integrated production, maintenance, and quality management. We began our research by examining the management of the three functions in pairs, starting with integrated production and maintenance planning, and then addressing joint optimization of quality and maintenance decisions, and finally by exploring production integration and quality control. What also distinguishes our work is our approach to optimization and the use of tools to validate the results for each reference processed. As a result, we were able to provide a detailed and updated overview on the subject. From a structural point of view, the article first addresses the research methodology adopted, and then presents the results obtained and their structured analyses by proposing a categorization of the models. Subsequently, in the fourth section, the paper examines and discusses the state-of-the-art in integrated maintenance, production and quality management, with the aim of providing a synthesis that may prove useful for experts in this field. In addition, we highlight the limitations of the research and the existing gap. Finally, we conclude this paper by proposing perspectives for future studies.

2. Research methodology and classification of publications

In order to identify and classify the models of joint production, maintenance and quality management, and a well-structured literature search process was followed as shown in Figure 1. To be effective, the literature search was carried out within different search engines such as: Science Direct, Taylor & Francis, Scopus, IEEE Xplore, etc. In this respect, we initiated the literature search with the appropriate keywords: production, maintenance, quality control, imperfect process; linkage; Integration; modeling; optimization. Furthermore, the in-depth search requires the use of different possible combinations of the above-mentioned keywords.

Subsequently, we propose different classifications of the publications obtained according to the year of publication, the type of publication (article, conference, and book chapter), the geographical origin of authors, the contribution of the work and the research method used.

Publication year

The literature search resulted in the selection of 52 publications. The Figure 2 represents the number of publications during each year from the year 2005 until 2023.

The problem of joint management of production, maintenance and quality attracts the tension of several researchers. As a result, the number of publica-

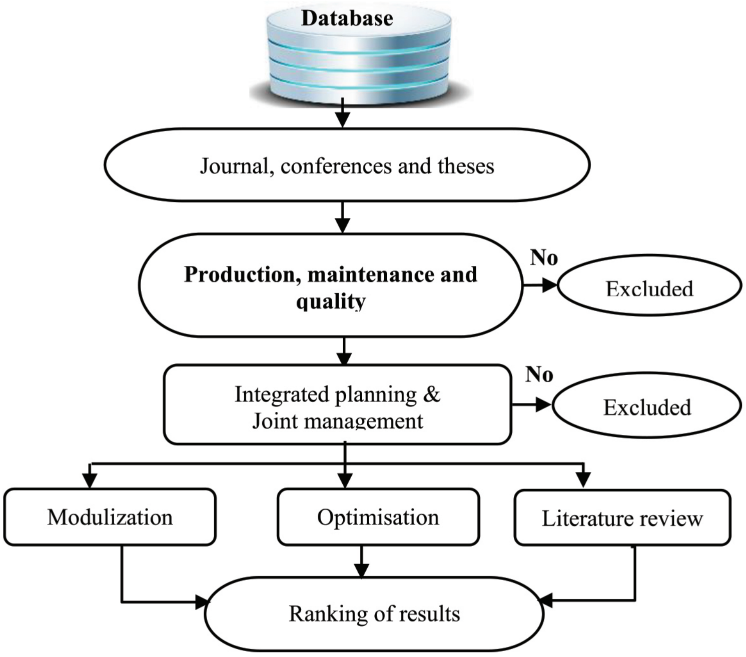

Figure 1. Document search process

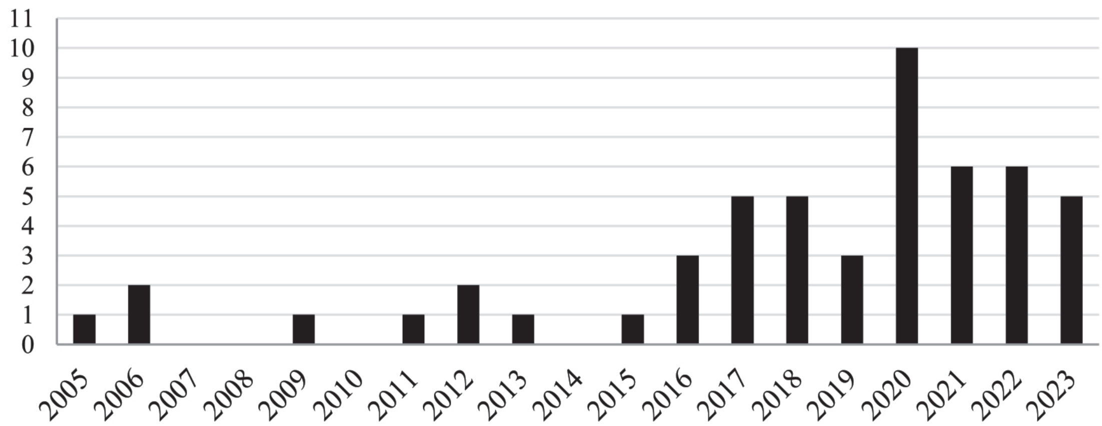

Figure 2. Evolution of joint production, maintenance, and quality management publications

tions has increased more and more in recent years, especially from 2017 to 2023, which indicates that this area represents a fertile field of research.

Publication type

Papers were selected from journals, conference proceedings and doctoral theses. Indeed, the selection procedure of the publications was not limited to a particular year. Certainly, to assess the relevance of a publication, we studied the title, abstract, conclusion and keywords. The Figure 3 shows the percentage of selected publications that are published in journals (41 papers), conference proceedings (9 papers) and doctoral theses (2 theses).

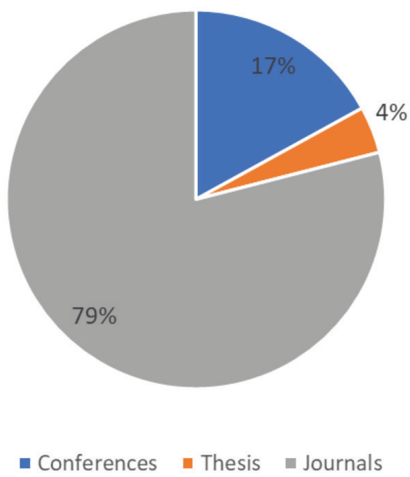

Figure 3. Percentage of publications by type

Geographical origin of the author

As shown in Figure 4, the majority of searches come from China, France and Canada. It comes after India, Morocco, Greece, Sweden, Mexico, and Saudi Arabia. Finally, Iran, Tunisia, Taiwan, Brazil, Italy, and Belgium contributed to the rest of the studies.

Contribution and method of research

The Figure 5 shows the classification of the publications according to the research method. Indeed, of the 50 publications (Journal publications and conference proceedings), 46 of them focused on the modeling of the integrated problem of production, maintenance, and quality. Then, the 4 articles developed a bibliographic study. Hence our interest to focus on the development of a literature review of the integration problem of the three functions.

3. Results and analysis

In this respect, we propose in the following a classification of the models existing in the literature that integrate the quality concept to the production and maintenance management such as (Figure 6):

- Joint optimization of quality and maintenance decisions;
- Integrated control of production and quality;
- Integration of production, maintenance, and quality strategies.

3.1. Integrated production and maintenance planning

Production management and maintenance management are mutually conflicting. The two departments have different objectives. Therefore, integration is necessary to address this problem [5].

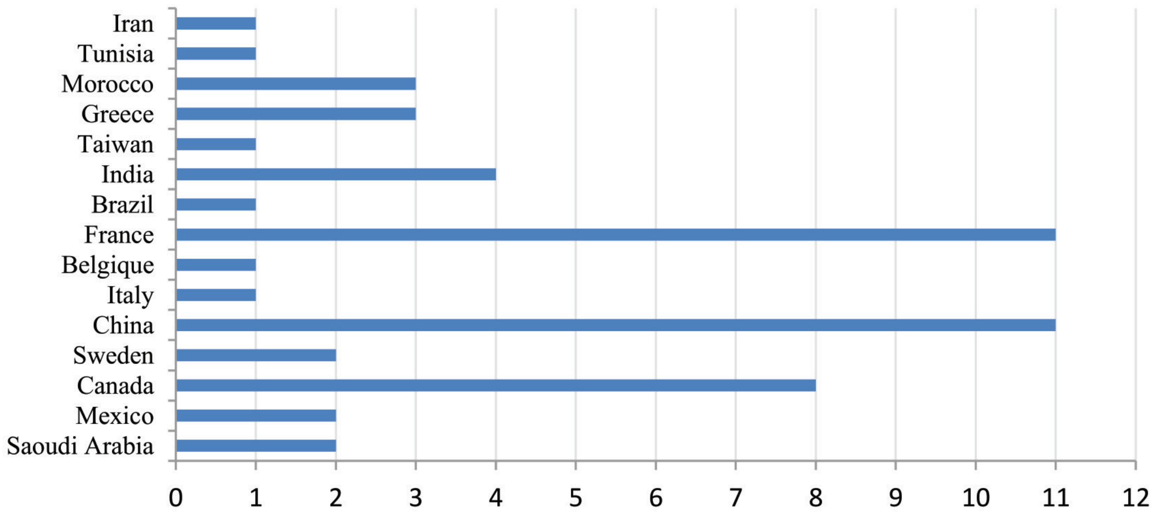

Figure 4. Number of publications by geographical origin of the author

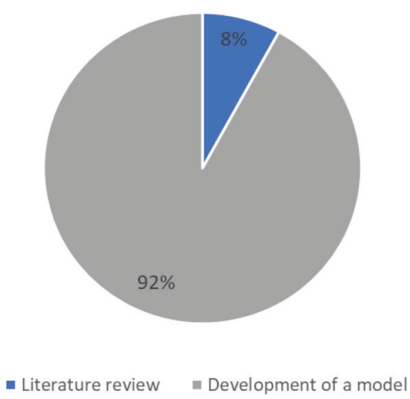

Figure 5. Percentage of publications by search method

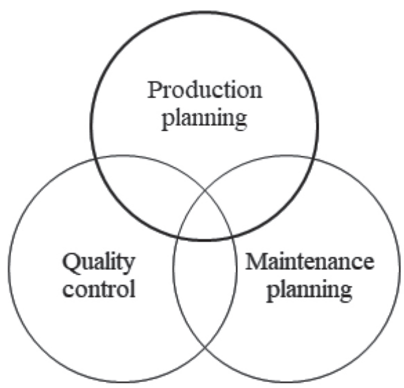

Figure 6. Joint production management of maintenance and quality

Reference [6] studied the integration of maintenance tools in cyber-physical production systems, using multi-criteria decision making. In addition, [7] addressed simultaneous maintenance and production planning decisions, using a simulation-based method. Then, reference [8] presented a predictive maintenance decision model for a single machine, minimizing the total cost. According to the literature search, we have drawn Figure 7. Its shows the classification of integrated production and maintenance models according to the main objective of the model.

Certainly, the modeling of machine deterioration is among the points to consider when processing integrated production and maintenance management models. Indeed, there are two types of machine deterioration. The first is known as random degradation, which means that deterioration occurs in an unpredictable manner over time according to a probability distribution. The second type is deterministic degradation. In this case, the deterioration increases in proportion to the elapsed time or production rate. [9] considered the dependency between the production rate and the failure rate. Equation 1 represents the failure rate $\lambda_k(t)$ at interval k as a function of the production rate U_k at time k and the maximum production rate U_{max}.

$$\lambda_k(t) = \lambda_{k-1}(\Delta t) + \frac{U_k}{Umax}\lambda_n(t) \quad \forall\, t \in [0, \Delta t] \tag{1}$$

In addition, the authors of reference [10] have modeled the machine degradation with the age of the machine a(t). The latter is defined as the number of products manufactured since the last intervention (minimal repair or preventive maintenance).

$$\frac{da(t)}{dt} = f(u(t)) \text{ with } a(0) = a \tag{2}$$

3.2. Joint optimization of quality and maintenance decisions

It is worth mentioning that there is a close link between the maintenance of production equipment and the quality of manufactured products. Indeed, the relationship between maintenance and quality depends on the conformity of manufactured products as well as the degradation of production equipment. In addition, we found in the literature that there are two approaches to planning maintenance actions and quality control [11]. The first approach is to use quality tools to determine the rate of rejection using the control chart [11], [12]. Regarding the second approach, it is expected that the production unit can have two states [13], [14]. The first state is called the under-control state, where the production unit produces products of acceptable quality. The second state is an out-of-control state in which the equipment produces second-choice (inferior quality) items or else non-conforming items (Figure 8).

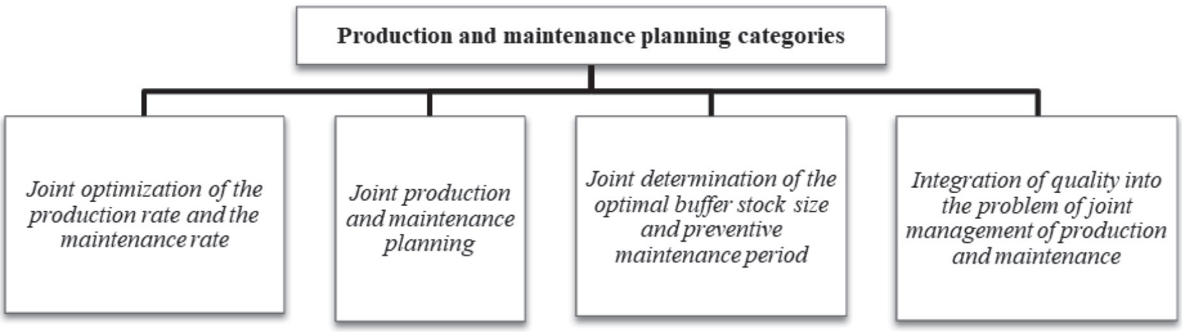

Figure 7. Production and maintenance planning categories

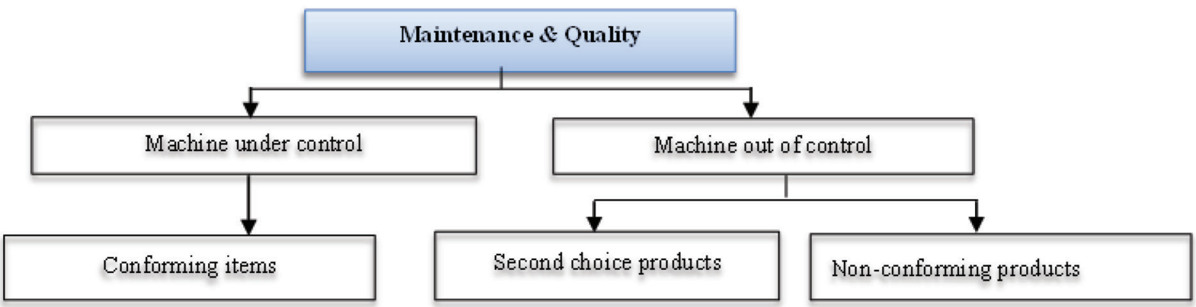

Figure 8. Maintenance and quality control planning

However, the increase in the rate of deterioration influences the quality of manufactured products, hence the need for preventive and corrective maintenance intervention. In the same context, [10] dealt with the joint control policy of maintenance and quality. The authors considered a production system with an increasing failure rate, the system produces conforming items as well as non-conforming ones. Their objective is to simultaneously determine the rejection rate and the optimal buffer size. In addition, [15] presented a joint optimization model for preventive maintenance and quality control using a control chart. In addition, the authors presented the impact of the manufacturing process on the final product reliability, assuming that the reliability degradation of the finished product is mainly due to manufacturing defects. Thus, [16] used an artificial neural network to predict the influence of machines on the quality of the final product. Indeed, the adopted conditional maintenance strategy is based on a threshold of the nonconformity rate, which justifies the link between the maintenance strategy and quality control. In this way, the quality-based conditional maintenance strategy was also the focus of the work of [17]. The authors showed that maintenance can reduce the deterioration of machines as well as the non-quality of manufactured products. Therefore, they proposed a conditional maintenance strategy based on the quality assessment of the finished products. Then, they suggested a comparison with a threshold that activates preventive maintenance actions. Note that most of the present research have confirmed a close link between maintenance and quality. Recently, [18] examined the role of quality adjustment on reducing the cost of the maintenance program. Khanh et al [18] proposed a Markov decision process based on a dynamic maintenance and inspection policy. On the other hand, [19] addressed the concept of quality, from the quality perspective of maintenance actions. The reference [19] introduced a random variable that identifies the quality of maintenance.

3.3. Integrated production and quality control

The management of the production service is generally linked to the quality of the service. The quality control of finished or in-process products is carried out either by sampling or by 100% quality control, depending on the criticality of the product manufactured. Quality control and process inspection are necessary to assess the state of the system, detecting instantaneous variations in the process.

Among the problems of production systems is the lack of quality of manufactured products. Based on this fact, the products of inferior quality are not usually sold at their regular price. In other words, inferior products are sold at a lower price. In fact, there are companies that favor the implementation of rework actions for inferior items. However, the decision to adopt the rework strategy depends on the criticality of the product. To clarify, if the product is of higher criticality, the likelihood of performing the rework action is minimal. In addition, process inspection and quality control can assess the hidden state of a system and detect process variations [20].

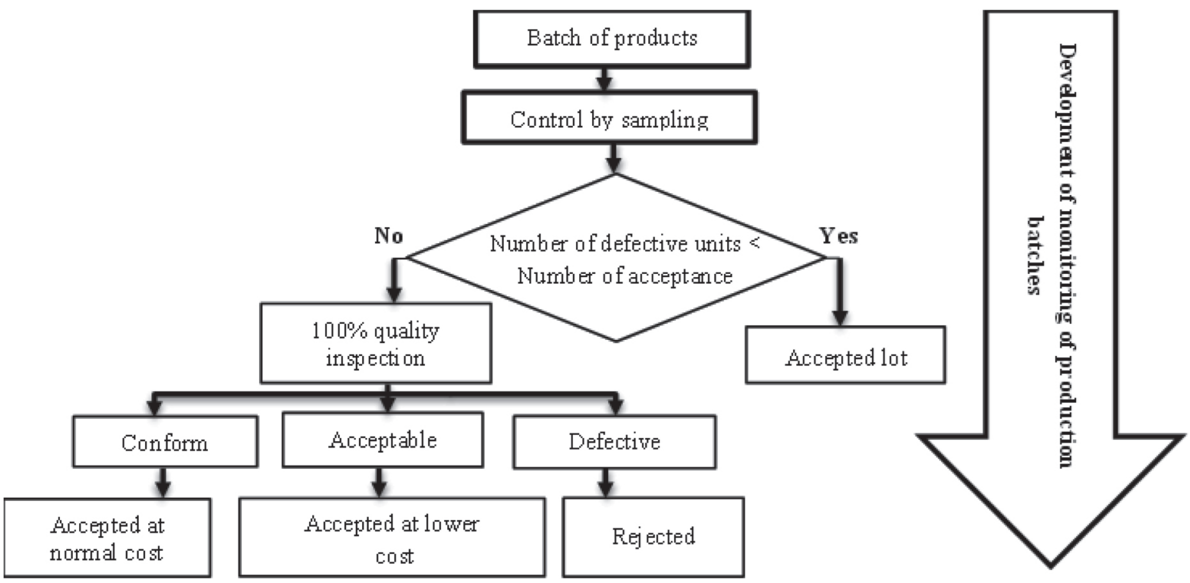

Figure 9. Development of monitoring of production batches

In addition, [21] addressed the problem of improving quality and production performance during the system ramp-up phase. Nevertheless, the products differ in price and quality level [22]. [22] examined the impact of infinite production capacity on optimal quality decisions. Figure 7 shows the different stages of quality monitoring of production batches [23].

3.4. Integrated management of production, maintenance, and quality

Conventional planning models assume that all products have acceptable quality. Nevertheless, the production system produces good quality and lower quality products. Thus, planners may give importance to some functions and others less. Recently, researchers have become more interested in imperfect production systems. Figure 10 summarizes the joint production, maintenance, and quality management work. Indeed, there are works dealing with the joint management of the three functions (production, maintenance, and quality) with and without the subcontracting constraint. We note that the integration of the three functions in the same model is new in the literature. Generally, the joint modeling consists in determining the production quantity, the number of preventive maintenance actions and the inspection rate.

Note that there is a classification of mathematical models, namely deterministic models, and stochastic models. Indeed, stochastic models differ by the randomness. On the other hand, there is no chance with deterministic models, i.e. we systematically obtain the same results for a given set of inputs. At the level of joint production, maintenance and production management, Table 1 shows the models that are deterministic and the stochastic models.

We notice that most models are stochastic rather than deterministic. Indeed, we can justify the choice of stochastic models because they are close to reality. Therefore, these models can be applicable in the industry. There is a lack of reviews of this type of integrated models. This category of problem is poorly studied in the literature. Indeed, the references considered a manufacturing system consisting of a single machine or a production line, manufacturing one or more products. In principle, joint modelling determines the production rate, the frequency of preventive maintenance measures, the inspection rate, etc. The results of our analysis of existing documentation show that:

- The joint management of the trio allows avoiding conflicts between the departments, to maximize the company's profits and to improve its performance;
- The majority of the works generally treat the simple case (only one machine / only one product) [8];
- The variation of the production rate influences the deterioration of the equipment [9];

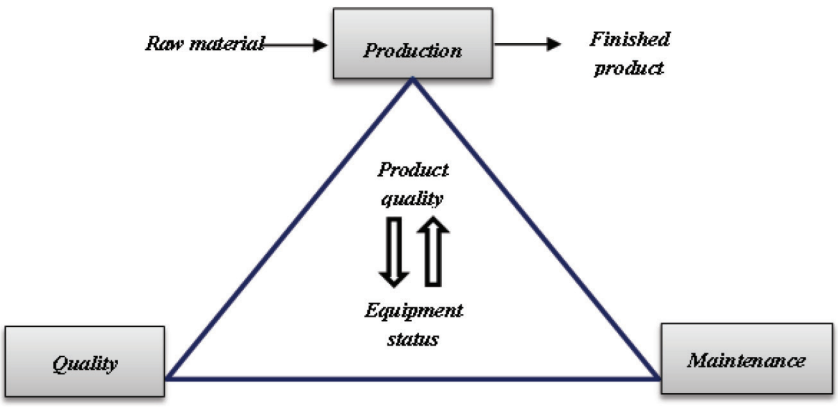

Figure 10. Synthesis of the joint management of production, maintenance, and quality

Table 1. Classification of deterministic and stochastic models

Model type	References
Deterministic models	[20], [31], [35], [37], [40]-[43], [49], [51], [52], [54], [55], [60], [62], [63]
Stochastic models	[24]-[30], [32]-[34], [36], [38], [41], [44], [45], [47], [48], [50], [53], [56]-[59], [61]

- The deterioration of the production equipment influences the quality of the manufactured products [15]-[18];
- The increase in the rate of deterioration leads to an increase in the rate of defective parts [22];
- Maintenance strategy influences equipment deterioration and failure rate [9], [20];
- Production systems with buffers [30], [31], [44], [48];
- Production planning includes a capacitated lot-sizing problem [20], [43], [44]. [47];
- Systems reflecting on energy consumption [34].

3.5. Optimization methods and validation of results

The mathematical models of joint production, maintenance and quality management generate complex optimization problems. Indeed, these problems can be deterministic or stochastic.

Consequently, to solve the joint problem, several parameters must be taken into account. The Table 2 presents the optimization methods of the production, maintenance, and quality integration models.

According to Figure 11, we notice that 30% of the models used the simulation and optimization approach as well as meta-heuristic methods. In addition, 16% is devoted analytical methods in order to solve the models of integration of production, maintenance and quality strategies. The remaining percentages are devoted to heuristic methods and dynamic programming.

Indeed, after the optimization step, the validation step of the results is essential. This step consists of several methods. Among the most used methods are:

- The case study,
- Sensitivity study,
- Comparative study with literature: that is to say, the results found were compared with those of other authors' work in the literature,
- Simulation or experimentation.

The following Table 3 represents the method(s) of validation of the results of the articles of integration of production, maintenance, and quality, of which the mathematical modeling is one of its objectives. Nevertheless, the authors can choose to use one or more validation methods.

4. Discussion

This document presents a literature review of existing models of joint production, maintenance, and quality management. However, the review shows

Table 2. Classification of integrated production and maintenance management models

The optimization method	References
Simulation optimization approach	[24]-[34]
Heuristic method	[20], [35], [36]
Analytical method	[37]-[40], [62], [67]
Meta-heuristic method	[32], [41]-[45], [52], [55], [64], [66], [68]
Dynamic programming	[53], [61]
Other	[46]-[48], [60]

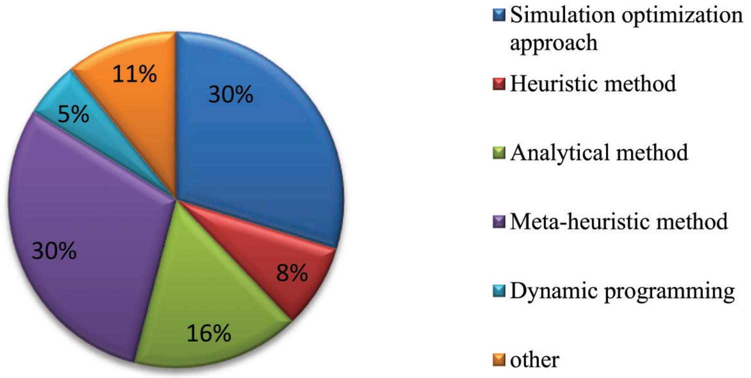

Figure 11. The percentage of publications according to the optimization method

Table 3. Classification of references according to the validation method

References	Case study	Sensitivity study	Comparison with the literature	Experimentation or simulation
[20]		√	√	
[24]		√	√	
[25]		√	√	
[26]	√	√		
[27]	√	√	√	
[28]	√	√		√
[29]	√	√		
[30]	√	√	√	
[31]	√			√
[32]	√		√	
[33]	√			
[34]	√			
[35]	√			
[36]	√	√		
[37]	√	√		
[38]	√	√		
[39]	√	√		
[40]	√			
[41]	√			
[42]	√			
[43]	√	√		
[44]	√	√	√	
[45]	√		√	
[46]			√	
[47]	√			
[48]	√	√		
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[64]		√		
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[67]	√			
[68]			√	

that, on the one hand, the strong dependence between the three functions mentioned above. On the other hand, the modelling of the degradation of the machines is a point of which linked between the three functions production, maintenance, and quality. For this purpose, the maintenance can reduce the degradation of the machines as well as the non-quality of the products manufactured, while guaranteeing the gain of the company. Therefore, an overview of production, maintenance and quality integration models is presented in this document, based on a review and classification of existing references.

In this study, 52 models were identified. These models date from 2005 to 2023. This field of study has attracted the attention of researchers in different countries around the world, producing different types of publications (journals, conference proceedings and doctoral theses). In addition, the classification of this review was done to group the models in terms of their purpose, with the aim of improving the clarity of the concept.

In order to reach the stage of studying joint management of production, maintenance and quality, different sections have been preceded. Some models have focused on integrated production and maintenance planning. Then, others studied the joint optimization of quality and maintenance decisions. In addition, other models have dealt with integrated production and quality control. The aim of this bibliography is to show that despite the different objectives of each department, whether production, maintenance or quality, their joint management makes it possible to guarantee the overall interest of the company.

In most industrial production organizations, the quality of items is often imperfect [69] and [48]. Indeed, the imperfect system represents the production system existing in the reality of industries. This system does not always produce good quality products. In other words, the quality of the products produced is not necessarily guaranteed (Figure 12). [29] defined the imperfect production system (IPS: Imperfect production system) as a production system that deteriorates in a progressive way with use as well as the quality of the manufactured products depends on the level of degradation of production equipment. However, many causes are responsible for the defectiveness of manufactured products such as, machine breakdowns, human errors and incorrect specifications [69]. Thus, inadequate process control, poor maintenance planning and inappropriate work instructions can also lead to the defective items [70]. Nevertheless, the defective parts manufactured by the IPS can be reworked or else rejected [71]. Under these circumstances, the customer can return the orders for exchange or request a refund in case of delivery of the non-conforming products [48].

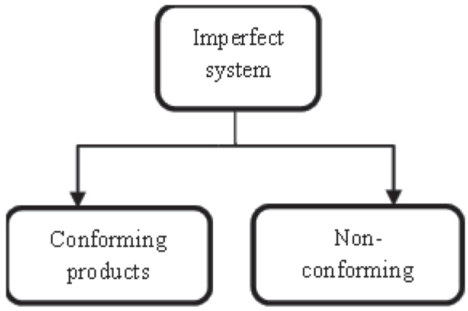

Figure 12. Imperfect production system

The traditional approach to quality usually occurs during the final stages of the production phase [72]. On the other hand, several products may be produced before performing product inspection [73], which results in significant losses for the company. From the quality point of view, the machine has two states, the first is "in control" and the second represents the "out of control" state. Thus, the passage to the 'out of control' state leads to the appearance of non-conforming products. However, the probability of moving to the 'out of control' state has a given value for each item produced [74]. To this end, repairs and rework are necessary to meet customer quality requirements [72]. Therefore, it is more reliable to consider that production is sometimes imperfect.

We point out that lot size problems are generally handled in a relatively stable framework. In other words, traditional QPS models are based on the assumption that a production process leads to parts of always perfect quality. Several researches have focused on batch sizing problems in production planning processing. [75] have addressed the multi-product capacitated batch sizing problem (MCLSP). The authors proposed an integrated production and maintenance optimization model, which aims at determining the optimal integrated production and maintenance plan. Reference [76] also studied the MCLSP problem, integrating the production planning and preventive maintenance strategy for a single machine. Their goal is to minimize the sum of production, storage, setup, breakage, preventive maintenance (PM) and minimum repair (MR) costs. We point out that an extension of dynamic batch sizing models to multiple products is the consideration of the cost of variation in production setup time. [77] considered the production environment is time varying. Their model considers setup costs, storage costs, and production capacity. They proved that their model allows them to search for high-quality solutions efficiently. Subsequently, [78] addressed the issue of economic production quantity (EPQ) in the context of joint production and maintenance management. The main purpose is to simultaneously determine the optimal number of inspections, inspection interval, EPQ level and PM level. More recently, [61] investigated an EPQ model for a production and maintenance integration issue. According to [79], the production system produces both compliant and non-compliant items. A preventive maintenance strategy is scheduled to reduce the deterioration of the system. Simultaneously determining the production lot size and PM schedule was its main concern.

We note that the batch sizing problem is widespread in the literature. The production capacity is assumed, in principle, to be constant over the planning horizon. In this spirit, the interaction between production, maintenance and quality control plans requires joint planning in order to improve the overall efficiency of the company. In the last decades, the integrated planning of production, maintenance and quality has appeared in the literature. Indeed, the availability of production equipment and the quality of manufactured products affect production planning. Based on our research, we found that the joint management models for the three functions are recent in the literature.

Given the complexity of multi-machine and multi-product systems for modeling and optimization, the research has jointly studied the three functions usually deals with the case of a simple production system consisting of a single machine producing a single product type. Recently, [80] studied the case of a deteriorating production machine, which produces both conforming and non-conforming items. They assumed that the deterioration of the production system has an impact on the quality of the manufactured products. PM actions are implemented to reduce the deterioration of the system. Their goal is to optimize the sum of production, storage, maintenance, and defect costs. [37] considered that a production system subject to a random failure rate, manufacturing three types of items such as:

- High quality conforming items;
- Lower quality items;
- Non-conforming items.

In order to improve the quality of second order and non-conforming products, a rework activity is performed. Their goal is to simultaneously determine the number of batches produced and the number of preventive maintenance actions. Other references have been extended from the single machine case to multiple machines. [81] jointly addressed production, maintenance, and quality for a manufacturing system consisting of a production line. The authors used simulation to model their system. Their goal is to simultaneously determine the non-conformance thresholds and the maximum rate of non-conforming units as well as the inventory size. In addition, [20] treated a production system consisting of the parallel machines manufacturing multi-products. The authors studied the CLSP problem, with the aim of determining the PM level, the number of inspections, the production rate, the out-of-stock rate, and the inventory rate. To solve the problem, the authors used genetic algorithms and taboo search. In the same context, the approach of [82] is to integrate production, maintenance, and quality for a batch size problem in the multi-product, multi-period case. The objective is to jointly select the optimal values for the production plan and maintenance policy, taking into account the quality costs. The research work of [28] has also jointly optimized the production, quality control and maintenance of a production line. Their study consists of proposing a combination of a mathematical model and a numerical simulation to simultaneously determine the optimal values of three decision variables namely PM age, quality control level and inventory level. Similarly, [83] studied the problem of integrated maintenance planning in production, the objective being to determine an optimal production and PM plan, while simultaneously minimizing production and preventive maintenance costs.

In summary, we have noted the importance of the coupling between the three functions of a company: production, maintenance, and quality. We note that the integrated management of at least two functions leads to a good management by maximizing the profit of the company. Whereas the separate management of production, maintenance and quality does not allow reaching the global objectives set by the company.

Therefore, this paper represents an addition to the literature. Indeed, the framework developed is relevant for two reasons. First, it provides an overview of the impacts of each function (production, maintenance, quality) on the reliability and availability of manufacturing equipment as well as on productivity; this can help different industry practitioners in decision-making. The approaches consider a manufacturing system composed of a single machine or a production line manufacturing one or several types of products. In general, joint modeling aims at determining the production rate, the frequency of preventive maintenance actions and the inspection rate.

5. Limitations and research gaps

Indeed, it is difficult to reconcile production, maintenance, and quality within a single model. Following our investigation, we found that this area represents a recent field of study. Therefore, existing models have research limitations. There is a gap between research and industry practice. Industrial production systems are often complex, while the literature generally focuses on simpler cases to facilitate modeling and problem solving. We have noticed a notable lack in the current literature regarding the consideration of the quality of manufactured products. Most models assume that all manufactured products are compliant, without taking into account that parts produced by degraded machines can be both compliant and non-compliant.

Specifically, integrated production, maintenance and quality management ensures maximum production efficiency and profitability. In addition, the integrated models of the management of the three functions make it possible to determine simultaneously the optimal number of preventive maintenance actions, the duration of time intervals between two successive maintenance actions, production quantity and inspection rate. However, it is essential to determine other parameters, such as sample size, sampling frequency, control limit coefficient, regulator stock size and sampling interval.

To achieve higher levels of efficiency, it is imperative to fully understand the interconnections between production planning, maintenance planning and quality control in different production systems. Although preliminary studies have established some correlation between these areas, it is imperative to conduct further research in this regard. Given the gap between research on joint management and industrial practice, the objective of this article is to encourage investment in the integration of production, maintenance, and quality, to increase the applicability of these models in the industrial context.

6. Conclusion and perspectives

This paper reviewed the problem of joint management of production, maintenance, and quality strategies. The aim of the study is to give an idea to practitioners and researchers about the current state of research in this field and to discuss a way to increase the applicability of the study in the industry. The classification of the works showed that this field represents a fertile area of different types of research (article, conference, and thesis), touching several geographical areas. However, during the review, many articles discussed integrated production and maintenance planning. Then, other research focused on the one hand, on joint optimization of quality and maintenance decisions, and on the other hand, on integrated production and quality control. Finally, the most recent research focuses on the integration of the three strategies of production, maintenance, and quality in a simultaneous way.

The literature review showed that in most cases the production systems are considered imperfect, i.e., can lead to non-conforming items. On the other hand, degradation has an impact on the quality of products manufactured. Thus, the more degraded the equipment is, the more non-conforming the manufactured products are. Certainly, the maintenance strategy is essential to minimize equipment degradation and the probability of defective products. To improve the quality of non-compliant products, a reworking activity is carried out. The researchers use the problem of lot sizing to study these integrated models.

Thereafter, different optimization methods for integrated production, maintenance and quality models have been used such as the simulation and optimization approach and meta-heuristic methods. In addition, we found different tools to validate the results of these integrated models: case study, sensitivity study, comparison of results with the literature and experimentation or simulation.

As part of the future work, it is planned to perform mathematical modeling integrating simultaneous production, maintenance and quality management for a production system comprising several machines and allowing the manufacture of various products. In addition, it is essential that the maintenance strategy takes into account the degradation of equipment, in order to ensure their proper functioning. Similarly, preventive, or conditional maintenance actions must consider the evolution of the degradation of production systems to ensure their optimal performance.

Furthermore, new approaches must consider the fact that production systems are not always able to manufacture compliant products. In other words, to be closer to reality, production systems should be considered imperfect, producing both compliant and non-compliant products. However, subcontracting can be a solution for companies because it allows them to deliver compliant items. Future studies could examine the impact of subcontracting in terms of reducing equipment degradation and improving the quality of manufactured items.

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