Optimizing the Model of the Total Productive Maintenance in Civil Reconstruction Machinery with a Sustainable Development Approach

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Abstract
The present study aims at optimizing the total productive maintenance model in civil reconstruction machinery with a sustainable development approach. Creating and maintaining an information base for use in the analysis of the maintenance conditions and performance enables the removal of one of the biggest barriers existing on improving and developing the preventive programming affairs and executive activities' timing regarding the civil reconstruction machinery. Using the descriptive analysis method, the extant documents regarding Iran and other countries will be examined to form a theoretical framework and specify the effective scales for applied methods. Then, the study region will be defined using specialized and evidenced documents and, next, using a decision-making and evaluation technique, the scales and subscales' values are determined. After calculating the values assigned to each technique, considering their properties, and giving proper weights to each by means of DEMATEL technique, the best software will be selected for attribution works and its alignment with the sustainable development's objectives will be verified.

Keywords: productive net, mechanized management, sustainable development, CMMS, TPM.

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1 Introduction
During the early years of the 20^{th} century that the equipment were simple, the idle time was not so important but it has become presently a very significant parameter. Since the cost of the production cessation was not so much in the past as compared to the value of the equipment, the

repair was immediately carried out as soon as a technical flaw occurred [1]. The slogan was "repair could not be done until a flaw occurs". The repair perspectives seemed not to be undergoing any changes in line with preventing the breakdown in the segments and protecting and maintaining the assets [2].

With the maturity of the new systems during the past three decades and obtainment of very satisfactory results by the applying companies, many organizations and companies sought using and applying these systems worldwide. Firms and factories gained a lot of benefits from establishing a net system and the proper founding of the net organization with every system being also needful of appropriate instruments for reaching an optimal output [3]. Technical managers and experts were faced with net systems with a large volume of data utilized for comparison, analysis, decision-making and on-time intervention. The large volume of the existing information, the necessity for the accuracy of the information, the proper storing of it, the speedy use and so forth were among the shortfalls of a manual system, even if a pervasive and precise one [4].

Most of the systems currently being applied in the industrial and engineering affairs undergo failure and breakdown during periods of their operational life; resultantly, they would need maintenance and repair activities. On the other hand, in large organizations, effective and efficient organizing activities entail enjoying a comprehensive and dynamic system that receives the required information with acceptable quality in a timely manner and reacts properly [5]. The important matter under the current conditions in the advanced universal and Iranian industries is, to a large extent, the lack of an efficient computer system for the planning and controlling of a group of primary and fundamental repair and maintenance activities. This requirement stems from the expansion of the volume, diversity and complexity, machinery mechanisms, increase in the production amounts and speeds, need for responding to the customers from the perspective of quality, delivery date, price and ability to preserve and develop the industry in competitive economy governing the national and international levels [6].

Net computerized maintenance management systems (CMMS) entered the arena of existence about two decades ago. CMMS includes computer-based technology for exact and efficient management of the physical assets within the framework of the information, administrative and executive affairs' planning. Considering the daily increasing expansion of the sustainable development and the successful history and effectiveness of these systems in the other industries, their principled application in the area of the civil reconstruction machinery is deemed necessary for it is needed by the engineering and industrial communities [7]. The main duty of the CMMS is repair and maintenance, providing instruments for the management and improvement of the net activities by the equipment, installations and machinery of an organization. CMMS is applied to meet the needs of a system, and it is a cost-effective tool for managing the information in a repair system [8].

Small and intermediate-size civil reconstruction companies run traditional and old structures in their net sectors. The machinery repair is often carried out in them after the breakdown. This ends in the stoppage of the entire work in many cases. The main step in these companies is the running of S5, and, of course, it takes about six months to complete [9]. When the work environment is clean, the problems cannot be recognized well. The cleaning and organizing of the workplace help the teams see the problems; actually, the first measure is seeing the flaws. S5 is the foundation and infrastructure of the TPM system's establishment in an organization [10].

Running S5, the organization's personnel learn team work. S5 should also be run in the machinery area, with its executives being the corresponding drivers and officials. S5 is closely interlaced with the self-control net and provided by the self-controlling net [11]. Based thereon, the present study aims at optimizing the total productive repair and maintenance model (TPM) in the civil reconstruction machinery with a sustainable development approach [12].

2 Study's Theoretical Foundations

2.1 Computerized Maintenance Management System (CMMS)

The emergence of CMMS in the industry dates back to forming a preventive repair and maintenance approach. At first and using the timing-based approaches, CMMS applied the preventive net strategy for baring the occurrence of unplanned stops. With the formation of the novel approaches in the net technologies and the advent of modern methods and techniques, CMMS software packages kept pace with the progress in these methods. They provided the required facilities for archiving the information and performing the required calculations. The evolutions in the CMMS software packages date back to the changes in repair and maintenance methods.

CMMS' emergence in the industry pertains to the time preventive repair and maintenance approach had been adopted. At first, and using the timing-based approaches, CMMSs applied the preventive net strategy for baring the occurrence of unplanned stops. With the formation of modern approaches in the net technology and with the advent of novel methods and techniques, CMMS software packages, as well, kept on progressing and provided the facilities required for archiving the information and performing the calculations.

Recently, civil reconstruction companies (particularly the firms possessing a large number of civil reconstruction machinery), as well, have become fully aware of the value of these systems as a means of enhancing the repair and maintenance performance. The application of CMMS alongside the other systems causes the repair and maintenance to be concentrated on the very important and vital parts of the organization with the urgent repair and planning being consequently minimized. Considering the studies' results, the most substantial ideas offered in total productive repair and maintenance (TPM) can be categorized based on their TPM's performance considerations. These notions have been compiled in Table 1.

Table 1. Ideas offered in the area of TPM

Theories offered by the experts	Achievement of zero unplanned stops	Reduction in the sequence of the breakdowns to an acceptable level	Establishing the preliminary equipment conditions	Possibility of investigating the cost in the given periods	Controlling the personnel's performance regarding the reworks	Possibility of controlling the warehouses' inventory for the spare parts	Possibility of classifying the flaws and their reasons and breakdown and their reasons	Archiving the technical documents in the form of an integrated system
							Delay	
Seiichi Nakajima TPM	√	×	√	×	×	√	×	√
John Mowbray PM	√	×	√	√	×	√	×	×
Charles Williamson PM	√	×	√	√	×	√	×	×
Ruby Alvez CM	×	√	×	×	×	×	√	×
Edward Garibyan EAM	×	√	×	√	×	√	×	√
Jason Johnson CBM	×	√	×	√	×	√	×	×
Chris Mumford CMMS	×	×	√	√	×	×	√	√

Rona Palmer TBM	√	√	√	×	√	×	√	×

3 Study Method

This study can be considered as an applied research. The study method used herein is descriptive-analytical, considering the use of the library research method for investigating the literature existing in this area as well as the experiences of the other countries in the world, Iran included (Fig. 1).

Considering the scales extracted from the various resources for optimization and the conditions existing in the study domain, the TPM model's optimization potential was assessed. Then, considering the extant conditions in terms of the studies on the repair and maintenance management and knowing about certain cases like capital wastage in unuseful methods, an information base's formation is deemed necessary. The confidence level should be enhanced and the existing evidenced documents should be descriptively analyzed. Objectives, policies, and strategies should be set before offering some options for optimizing the total productive repair and maintenance model regarding the civil reconstruction machinery.

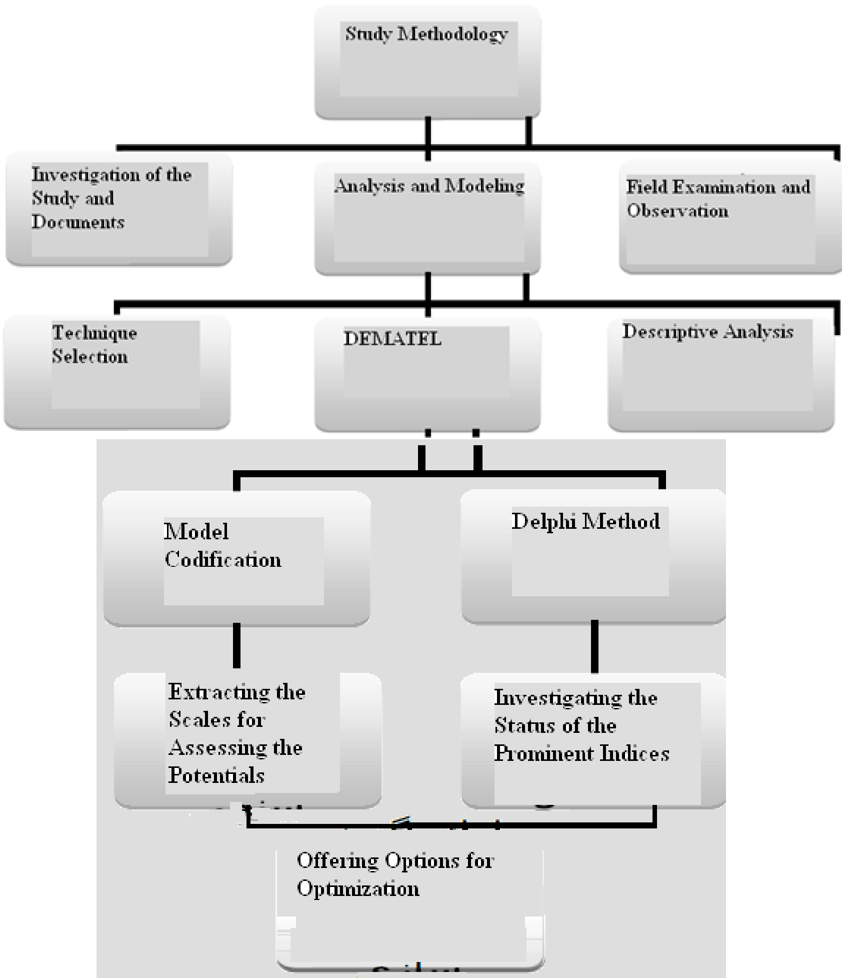


Fig. 1 Implementation method's process

Considering the results obtained from the analysis and using the Delphi method and based on the identification of the scales influencing the optimization and taking advantage of the weights obtained for each of them as well as the weights obtained for every kind of scale, a model of their effects on the repair and maintenance optimization has been offered. In this model, four subscales have been defined for each of the scales. Based on this model, the effect of the scales on the optimization of repair and maintenance can be determined. Amongst the other applications of this model is the prediction of the scales influencing the optimization of the repair and maintenance based on the futuristic approaches. In this way, optimizers evaluate themselves based on these identified scales.
Based on this evaluation, every scale is given a score between 0 and 100, which is a range indicating the amount of the scales' impact on the optimization of the repair and maintenance, with the largeness of this value being reflective of the high effect of these scales on the optimization of repair and maintenance. This model's concept and itself have been formulated as follows. The evaluation of the suggested options has been undertaken to optimize the total productive repair and maintenance system using the SWOT method.

4 Results

At the beginning of the Delphi method's implementation, 14 experts were identified, with 13 announcing their readiness to participate in the panel. In the continuation of the Delphi stages' implementation, four experts were separated from the panel, and the current members reached ten in number in the second round. Based thereon, the members of the Delphi panel were selected for this research in the form of non-probability and combined sampling using judgmental and purposeful methods. 60% of the final experts were male, and 40% were female. The highest frequency of the respondents' age pertained to individuals above 45 years of age.

4.1 Stages of Delphi Method

The Delphi method was carried out in this study in two rounds. In the first round, all of the panel members completed and delivered the questionnaires, and a total number of 13 questionnaires were analyzed. Table 2 gives the results of pairwise comparisons between the scales obtained from the Delphi method.

Table 2. Results of pairwise comparisons of the scales obtained from Delphi method

Scale A	9	7	5	3	1	3	5	7	9	Scale B
Functional	9	7	5	√	1	3	5	7	9	Processual
Effectiveness	9	√	5	3	1	3	5	7	9	
Expenitures	9	7	√	3	1	3	5	7	9	
Confidence	9	7	5	3	1	3	√	7	9	
Human workforce	9	7	5	3	1	3	5	√	9	
Qualitative	9	7	5	3	1	3	5	7	√	

Interested parties' satisfaction	9	√	5	3	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	3	√	7	9	
Effectiveness	9	7	√	3	1	3	5	7	9	Functional
Expenditures	9	7	5	√	1	3	5	7	9	
Confidence	9	7	5	3	1	3	√	7	9	
Human workforce	9	7	5	3	1	3	5	√	9	
Qualitative	9	7	5	3	1	3	5	7	√	
Interested parties' satisfaction	9	7	√	3	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	3	√	7	9	
Expenditures	9	7	5	3	1	√	5	7	9	Effectiveness
Confidence	9	7	5	3	1	3	√	7	9	
Human workforce	9	7	5	3	1	3	5	√	9	
Qualitative	9	7	5	3	1	3	5	7	√	
Interested parties' satisfaction	9	7	5	√	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	3	5	√	9	
Confidence	9	7	5	3	1	3	5	√	9	Expenditures
Human workforce	9	7	5	3	1	3	√	7	9	
Qualitative	9	7	5	3	1	3	5	7	√	
Interested parties' satisfaction	√	7	5	3	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	3	√	7	9	
Human workforce	9	7	5	3	1	3	√	7	9	Confidence
Qualitative	9	7	5	3	1	3	5	√	9	

Interested parties' satisfaction	√	7	5	3	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	√	5	7	9	
Qualitative	9	7	√	3	1	3	5	7	9	Human workforce
Interested parties' satisfaction	√	7	5	3	1	3	5	7	9	
Environmental aspects	9	7	5	√	1	3	5	7	9	
Interested parties' satisfaction	√	7	5	3	1	3	5	7	9	Qualitative
Environmental aspects	9	7	√	3	1	3	5	7	9	
Environmental aspects	9	7	5	3	1	3	5	7	√	Interested parties' satisfaction

Fig. 2 displays the superior indices obtained from the Delphi method.

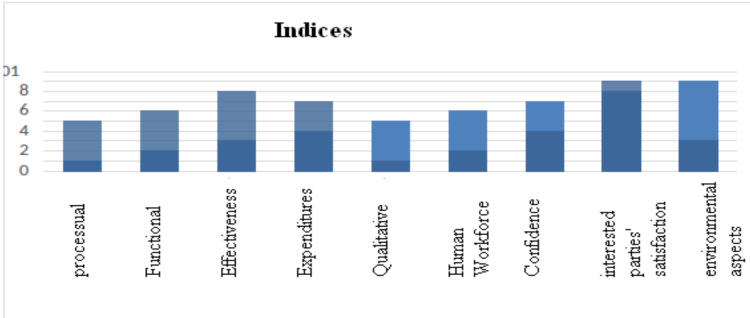


Fig. 2 The superior indices obtained from the Delphi method

The second part of the Delphi method offers a list of optimization challenges extracted from previous research. Fig. 3 exhibits the ranking of the challenges extracted from the prior research.

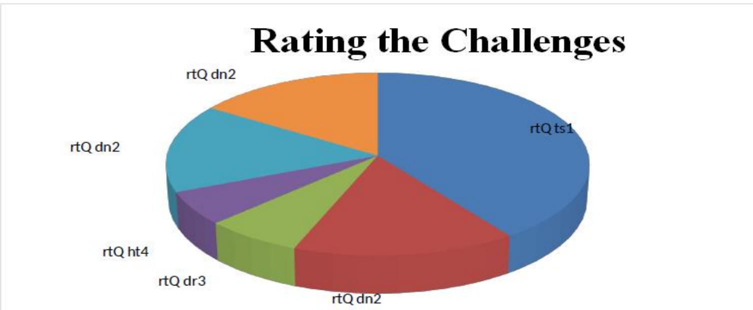


Fig. 3 Challenges' ranking

The forthcoming section uses the DEMATEL method to display the direct relationships between the six factors of A, B, C, D, E and F (Fig. 4).

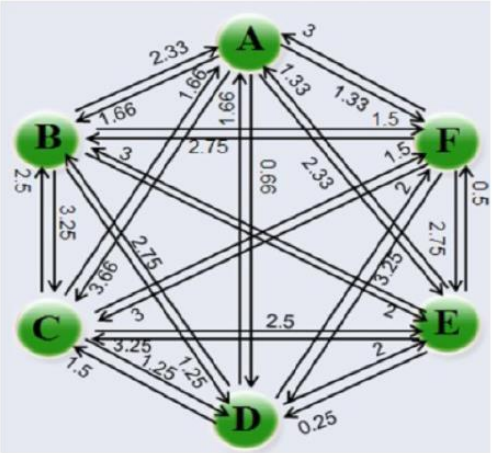


Fig. 4 Diagram of the direct relationships

Sum of Lines

$$M=\begin{bmatrix} 0 & 1.66 & 3.66 & 0.66 & 2.33 & 1.33 \\ 2.33 & 0 & 3.25 & 1.25 & 2 & 1.5 \\ 1.66 & 2.5 & 0 & 1.25 & 2.5 & 1.5 \\ 1.66 & 2.75 & 1.5 & 0 & 2 & 2 \\ 1.33 & 3 & 3.25 & 0.25 & 0 & 0.5 \\ 3 & 2.75 & 3 & 3.25 & 2.75 & 0 \end{bmatrix} \begin{matrix} \Rightarrow & 9.64 \\ \Rightarrow & 10.33 \\ \Rightarrow & 9.41 \\ \Rightarrow & 9.91 \\ \Rightarrow & 8.33 \\ \Rightarrow & 14.75\,max \end{matrix}$$

$$\alpha=\frac{1}{14.75}=0.0678$$

In the second step, the matrix of the direct relationships is created.
In the third step, Matrix M is normalized.

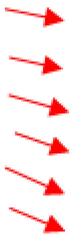
$$N=\alpha\,.\,M=\begin{bmatrix} 0 & 0.1125 & 0.248 & 0.045 & 0.158 & 0.09 \\ 0.158 & 0 & 0.22 & 0.085 & 0.135 & 0.1 \\ 0.112 & 0.17 & 0 & 0.85 & 0.17 & 0.1 \\ 0.112 & 0.186 & 0.1 & 0 & 0.135 & 0.135 \\ 0.09 & 0.2 & 0.22 & 0.017 & 0 & 0.034 \\ 0.2 & 0.186 & 0.2 & 0.22 & 0.186 & 0 \end{bmatrix}$$

In the fourth step, inverse matrix calculation is conducted.

$$(1-N)^{-1} = \begin{bmatrix} 1.4643 & 0.7068 & 0.8530 & 0.9596 & 0.6833 & 0.4406 \\ 0.6194 & 1.6252 & 0.8549 & 1.0062 & 0.6845 & 0.4629 \\ 0.8926 & 1.1867 & 2.0697 & 2.0774 & 1.0680 & 0.7227 \\ 0.5420 & 0.7249 & 0.7029 & 1.7943 & 0.6299 & 0.4552 \\ 0.4883 & 0.6950 & 0.7502 & 0.8208 & 1.4743 & 0.3494 \\ 0.7967 & 0.9697 & 1.0378 & 1.3420 & 0.8904 & 1.4839 \end{bmatrix}$$

In the fifth step, the matrix of total relationships is computed.

sum of lines R



$$S=N(1-N)^{-1}=\begin{bmatrix} 0.646 & 0.7068 & 0.8530 & 0.9596 & 0.6833 & 0.4406 & 4.1 \\ 0.6194 & 0.6252 & 0.8549 & 1.0062 & 0.6845 & 0.4629 & 4.25 \\ 0.8926 & 1.1867 & 1.0697 & 2.0774 & 1.068 & 0.7227 & 7.00 \\ 0.542 & 0.7249 & 0.7029 & 0.7943 & 0.6299 & 0.4552 & 3.85 \\ 0.4883 & 0.695 & 0.753 & 0.8208 & 0.4743 & 0.3494 & 3.58 \\ 0.7967 & 0.9697 & 1.0378 & 1.342 & 0.8904 & 0.4839 & 5.25 \\ 3.8 & 4.9 & 5.27 & 7.1 & 4.43 & 2.91 & \end{bmatrix}$$

Sum of Columns J

Then, the contingent intensities are calculated in the sixth step using indirect relationships.

$$\begin{array}{c} \quad A \quad\quad B \quad\quad C \quad\quad D \quad\quad E \quad\quad F \end{array}$$

$$T = N^2(1-N)^{-1} = \begin{bmatrix} 0.464 & 0.59 & 0.6 & 0.91 & 0.525 & 0.35 \\ 0.46 & 0.625 & 0.63 & 0.92 & 0.55 & 0.36 \\ 0.78 & 1.00 & 1.07 & 1.22 & 0.9 & 0.62 \\ 0.43 & 0.54 & 0.6 & 0.8 & 0.5 & 0.32 \\ 0.4 & 0.5 & 0.53 & 0.8 & 0.47 & 0.315 \\ 0.6 & 0.78 & 0.84 & 1.12 & 0.7 & 0.48 \end{bmatrix}$$

It is observed in this matrix that the main diameter is non-zero in all of the entries, and this means that these elements also influence one another (Fig. 5).

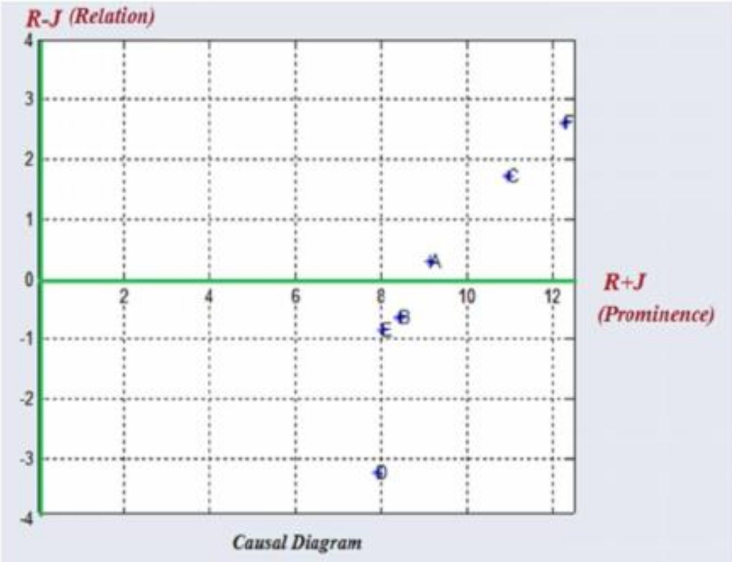


Fig. 5 The causal diagram

Considering the results obtained from the analyses and based on the identification of the scales influencing the optimization and the weights obtained for each of them and the weights of each kind of the scales, a model has been offered for optimizing their effects on the repair and maintenance. In this model, four subscales have been defined for each of the scales' kinds.

Based on this model, the number of the scales' effects on the optimization of repair and maintenance has been determined. Amongst the other applications of this model is the prediction of the scales influencing the optimization of the repair and maintenance based on a futuristic approach. In this way, such optimizers evaluate themselves based on these identified scales. Based on this evaluation, each scale is given a score between zero to 100 which indicates the extent to which the scales influence the optimization of the repair and maintenance; so, the larger the magnitude of this value, the higher the effect of these scales on the optimization of repair and maintenance. This concept and model have been formulated as below:

$W_i=\{1,\dots,4\}$ Weight of each of the optimization scales' kinds

$W_{ij}=)x_1,\dots,x_n)$ Weight of each of the corresponding optimization scales

$X_{ij}= (0,100)$ Value obtained in the evaluation of the contrastive and corresponding optimization scales

$T= (0,100)$ Amount of the success in the application of the optimization scales influencing the repair and maintenance

$$T= w_1 \sum W_{1i}X_{1i} + w_2 \sum W_{2i}X_{2i} + w_3 \sum W_{3i}X_{3i} + w_4 \sum W_{4i}X_{4i} + w_5 \sum W_{5i}X_{5i} + w_6 \sum W_{6i}X_{6i}$$

Fig. 6 shows the model of the scales influencing the optimization of the total productive repair and maintenance.

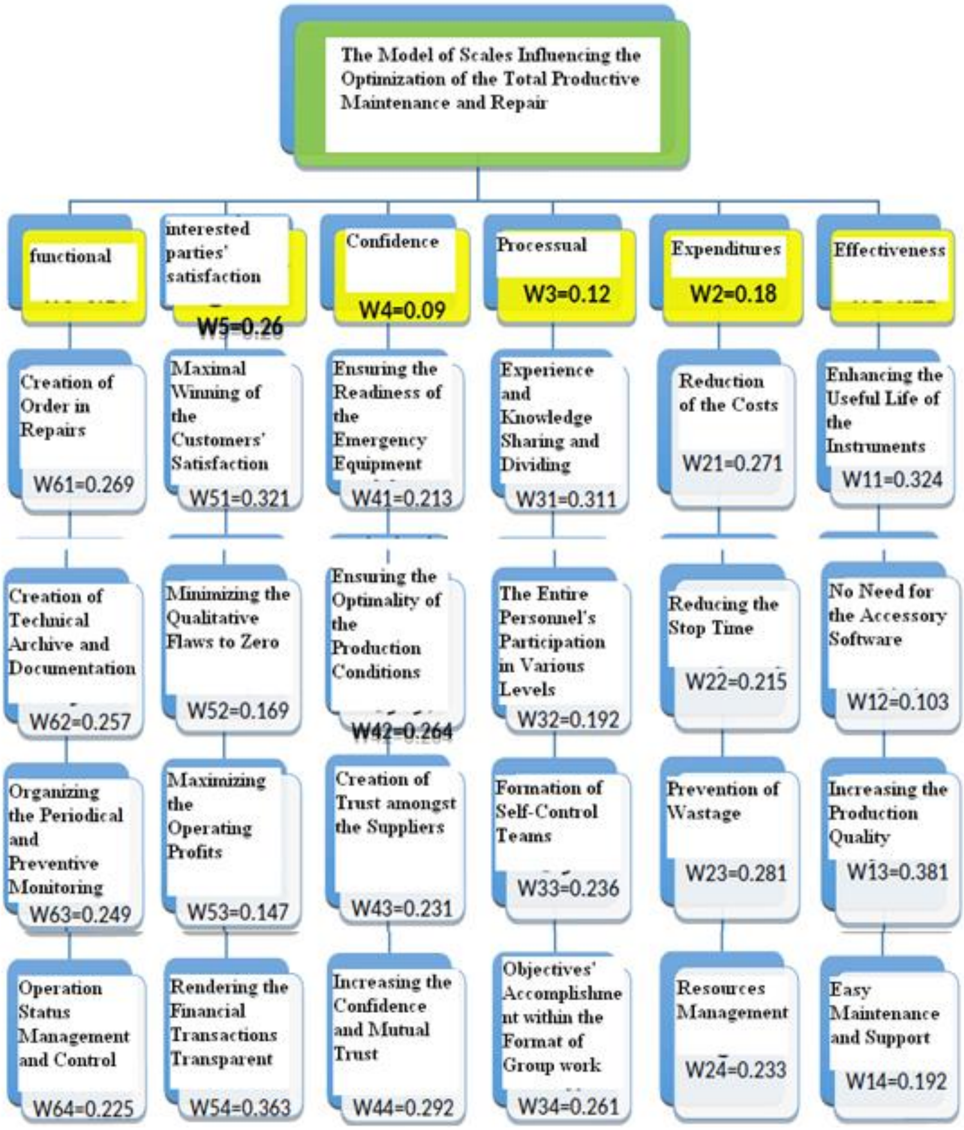


Fig. 6 The model of the scales influencing the optimization of the total productive repair and maintenance

In the proposed model, each of the optimization scales is given a weight which means the degree to which the scales influence the optimization. On the other hand, each of the subscales, as well, is given a weight reflecting the extent to which each of the scales' kinds influences the optimization of the repair and maintenance. Among the other applications of this model, identification of the scales' weak and strong points and their effects on the optimization of the repair and maintenance can be pointed out. Additionally, companies use this model to engage in their self-evaluation before implementing the optimization framework and take advantage of this model in their decision-making.

5 Conclusions

The main goal of this research is the identification and presentation of a model of the scales' effect on the optimization of TPM for civil reconstruction machinery. Considering the results obtained from the prior research, various optimization scales can, among other things, be effectiveness, processes, expenditures, functions, confidence and interested parties' satisfaction. According to the results obtained from the analyses and based on the identification of the scales influencing the optimization and weights obtained for each of them and the weight of each of the scales' types, a model of their effects on the optimization of repair and maintenance has been offered. In this model, four subscales have been defined for each of the scales' kinds.

A computerized management system has is own special capabilities and limitations that form its structures.

Table 3. The existent and nonexistent descriptions regarding the computerized management system

The existent descriptions	The nonexistent descriptions
A software specific to the net activities	It should not be considered an automation software
Support the more up-to-date versions of the net's new approaches	Low support in the HRM
Support of purchase management in terms of net activities	Not a warehousing software
Direct relationship with GIS	Limited and exclusive support of ERP-assisting systems
Coordination with map-drawing programs and applications	It should not be mistaken for asset management systems
Preparing reports and collecting managerial information	CMMS systems do not include contractors' management
Support of the predetermined guidelines	Impossibility of changing the assigned tasks

One of the most important goals in computerized management is reducing or omitting the so-called six largest losses.

Table 4. The six largest losses and their three primary factors

Main factor	Six largest losses	TPM losses	Delay causing factors	Interpretation
Availability	Breakdown	Breakdown duration	Equipment breakdown Consideration of the maintenance program General breakdown	Relationships between the devises' breakdown (the

			Equipment breakdown	loss of the breakdown duration) and short stalls (the loss of speed reduction)
	Restarting, setting and changing	Breakdown duration	Setting up the change Shortage of the raw materials Essential setups Devise's readiness time	This loss often falls in the area of the duration of education plans
Equipment performance	Short stalls	Speed reduction	Slackening of the production race Improper feeding Sensors' malfunctioning Investigation of the cleanliness	Generally, includes the stops below five minutes that do not need the presence of the maintenance personnel
	Speed reduction	Speed reduction	Initial launching The low nominal capacity of the electrical panel Low designing capacity Equipment depreciation Operators' inefficiency	Everything that prevents the processing with maximum possible speed (the ideal speed of performance or the low nominal capacity of the electrical panel)
Quality	Flaws and reworks	Quality reduction	Segment Reworking Breakdown during production Expiration during production Improper assembling	Waste materials that are created during the preparation of the device, its launching and early stages of the production may come

				about as a result of improper launching or improper preparation period
	Flaws in launching	Quality reduction	Segment Reworking Breakdown during production Expiration during production Improper assembling	Waste materials produced during the continuous production

TPM method is less costly and less time-consuming than the traditional and common repair and maintenance method, i.e., repair after the breakdown. It enables the heightening of the machinery's efficiency. It increases the duration of the machinery's use (the mean time between two breakdown incidents) and increases the machinery's profitability for the companies.

Evaluating the options suggested for optimizing the total productive repair and maintenance using the SWOT analytical method is part of the optimization process. This analytical evaluation has been presented in the Table 5 format underneath.

Table 5. Evaluation of the options suggested using the SWOT method

Options evaluation	Strong points	Weak points	Opportunities	Threats
MKMS Software	Web-based organizational network Simple application and handling	Non-completion of some of the repairs and maintenance assignments Non-accomplishment of some of the repairs	Management of the physical assets Management of the repair and maintenance knowledge	Non-documentation of some of the tasks Non-documentation of some statistics
PM Works Software	Software's fault-finding module Software's planning module	Mismanagement of the existing resources Weakness in the various levels' of management	Equipment confidence's management Managing the connection with the	Inability to copy and transferring the information

			other organization's software packages	Weakness in controlling the materials' inventory
Alka Cloud Software	Recording the information of every user Extraction of the projects' reports	Non-establishment of the preliminary conditions Impossibility of investigating the costs	Financial definition and management of the projects Perfect introduction and management of the projects	Non-controlling of the personnel's performance Impossibility of controlling the warehouse's inventory
CMMS PRO software	Smart information providing system's module Form circulation and letter writing module	Impossibility of classifying the flaws Impossibility of archiving the technical documents	Staff members' information management Machnery's performance management	Non-reduction in the breakdowns' sequence Inability to achieve zero stops

According to the investigations, CMMS PRO is the best choice for this study's objectives. It can be stated that DEMATEL analysis is the best method for prioritizing the CMMS software packages.
Considering the results, the specialized CMMS software's is suggested for designing maintenance and repair of the civil reconstruction machinery and updating TPM techniques regarding the civil reconstruction machinery's repair and maintenance.

Data Availability Statements: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest: The authors declare that they have no conflict of interest.

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