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DETERMINATION OF BARRIERS PRIORITY THAT IMPACTS TO THE IMPLEMENTATION OF THE TPM CONCEPT BY USING GENETIC ALGORITHM

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Abstract The implementation of the TPM concept brings with it significant benefits for an enterprise, but also faces with numerous barriers that can obstruct the implementation process. Also, an inadequate implementation method can generate some additional problems. In this paper, the problem of barriers priority determination that affects the implementation of the TPM concept by using the Genetic Algorithm is considered. The main goal of this paper is to determine which barriers are the most important to the TPM concept implementation by applying this metaheuristic method, but also those barriers that could be more easily eliminated if the major impact barriers were eliminated first. The considered problem in this paper is set as so-called "P-Median" problem. So far, in the literature it has not been possible to find papers where this type of problem has been solved by the application of any of the metaheuristics or Multi-Criteria Decision-Making methods.

Keywords: Total Productive Maintenance; genetic algorithm; barriers; lean concept.

1. INTRODUCTION

There are many reasons for implementing the TPM concept. Starting with improving the effectiveness of production equipment, reducing the occurrence of write-offs products caused by the malfunction of production equipment, reducing the number (frequency) and time of downtime because of production equipment failure, reducing the level of intermediate supplies, reducing costs, etc. However, in order for the benefits of implementing the TPM concept to be tangible, it is necessary to implement this concept properly in the factory. A relatively long time period has to pass from the decision to start implementing the concept to the realization, and many barriers must be overcome through the implementation process that impede and slow down the implementation process.

The problem considered in this paper is the identification of the most important barriers, that is, those barriers that have the greatest impact on the TPM concept implementation. By using Genetic Algorithm, priority of barriers for elimination is given. The barriers discussed in this paper were identified during the implementation of the TPM concept in a factory that received the highest World Class Award for the implementation of the TPM concept by the Japan Institute of Plant Maintenance (JIPM).

The paper is organized in the following way: In second section the basic considerations about the Lean concept and World Class Manufacturing (WCM) is given. In section 3 the Total Productive Maintenance (TPM) is presented, as well as the barriers that have impact to implementation of this

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concept. The basics of metaheuristic methods and Genetic algorithm are given in fourth section. Section 5 presents an Illustrative example, while section 6 provides main conclusions of this research.

2. LEAN AND WCM CONCEPT – BASIC CONSIDERATIONS

Manufacturing companies in recent decades have been facing major changes in the market and changes in the way they do business, caused primarily by rising expectations and demands of customers, but also by increasing of competition. For this reason, the business policy of modern manufacturing companies is guided by the belief that customers are the most important factor influencing the business of the company and that the basic goal is to satisfy their requirements. At the same time, meeting customer demands leads to competitive advantage. Since the fulfillment of customer requirements must not be called into question, the management of an enterprise has an important strategic task which refers to creating strategy of increasing profits and reducing costs considering customer requirements and market conditions. In other words, Gotoh [1] believes that in order to remain competitive in a dynamic business environment, enterprises must constantly improve their offering of product and product characteristics, while increasing level of quality, reducing business costs and investing in research and development. These requirements can be achieved, inter alia, by applying the Lean concept. Lean production means production without unnecessary waste and dissipation of resources [2]. There is no universal definition of Lean in the literature. Some authors see it as a set of principles [3], some as a set of tools and techniques [4], some as an approach [5], some as a system [6], but some also as a concept [7]. In addition, Lean is often referred to as a philosophy, a production paradigm, operational management, practice, and the like [2]. In paper [3] the authors provide a comparison between Lean and traditional, mass production based on seven criteria (see table 1).

Table 1. Basic differences between Lean and mass production [3].

	Mass production	Lean production
Basis	*Henry Ford*	Toyota
Human resources – design	Narrowly skilled professionals	Teams of multi-skilled workers at all levels in the organization
Human resources – production	Unskilled or semi-skilled workers	Teams of multi-skilled workers at all levels in the organization
Equipment	Expensive, single-purpose machines	Manual and automated systems which can produce large volumes with large product variety
Production methods	Make high volumes of standardized products	Make products which the customer has ordered
Organizational philosophy	Hierarchical – management take responsibility	Value streams using appropriate levels of empowerment – pushing responsibility further down the organization
Philosophy	Aim for "good enough"	Aim for "perfection"

It should be emphasized that Lean production in compare with traditional not provides only benefits for the company but also for the customers. Unlike mass production, whose main characteristic is the production of large quantities of the same products, Lean production strives to meet customer requirements by producing different variations of products. In addition, employees in companies in mass production often see their work as always the same, tedious, and boring, which is another advantage of Lean production, which encourages creativity and motivation of employees [8]. Although the implementation of the Lean concept contributes significantly to improving the business

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of the company, it is not simple to do business according to Lean. Figure 1 shows the factors that may encourage or be reason for resist of the Lean concept implementation [8].

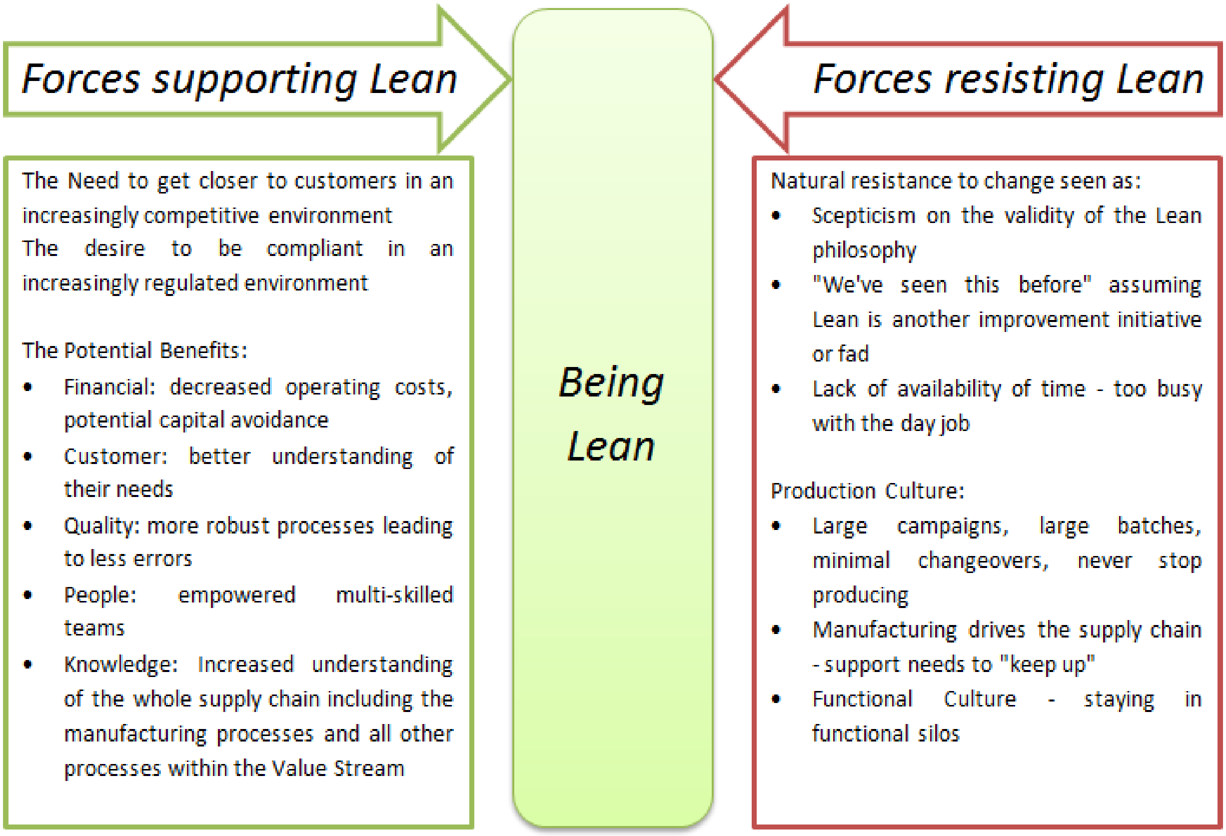

Figure 1. Forces supporting and resisting Lean [8].

From the Melton's analysis [8] can be concluded that the basic brakes in applying the Lean concept are actually ignorance and doubt about the results of the application. Proponents of traditional, mass production, see Lean as a fad and something that would significantly impede the normal functioning of the system. In such cases, even the potential benefits cannot be an incentive to attempt to implement the concept in such enterprises.

Based on the review of relevant literature and the experience transferred through scientific researches and papers, it can be concluded that the implementation of the Lean concept has multiple benefits for the business of the enterprise, but the consequences that the wrong way of implementation carries with it must be taken into account. For this reason, all the circumstances, which are reflected in the capabilities of the enterprise and subcontractors, the desired (expected) and possible outcomes of implementation, as well as whether the existing organizational culture is subject to radical change, must be considered.

From its inception in Japan as a Toyota production system, the Lean concept has been greatly improved to this day. However, it can be consider that the Lean concept is actually the basis for many other, much more complex, concepts that emerged decades later. One of the most famous concepts based, among other things, on Lean manufacturing philosophy is World Class Manufacturing (WCM). In fact, WCM has emerged as a set of concepts, techniques, methods and principles for

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managing and organizing a company and its business processes. In other words, WCM is a concept that sets standards for the production and business of organizations that intend to operate under this concept.

WCM is based on 4 methods/concepts. The first method is TIE, or Total Industrial Engineering, identified and defined by Hajime Yamashina and incorporates a set of methods and techniques by which labor productivity is increased by reducing 3M losses [9]. The TQC (Total Quality Control) method is a set of methods that is applied to eliminate the occurrence of write-offs and refers to the control and improvement of the quality of the production process. Total Productive Maintenance (TPM) is a concept that aims to increase the effectiveness of production equipment and to minimize the number of production equipment failures. The fourth method/concept is Just in Time, which aims to reduce the level of inventories of both intermediate and finished goods. These 4 methods lead to the implementation of a business philosophy called TQM (Total Quality Management or Total Quality Management), which aims to provide the desired product quality to customers and control the quality of products and processes from the entry of raw materials into the company to exit of finished products from the company [10].

The success of WCM implementation is directly determined through the evaluation program of the companies implemented by the relevant certification bodies. The most famous certification body that conducts the WCM evaluation process at companies is the Japan Institute of Plant Maintenance (JIPM).

3. TOTAL PRODUCTIVE MAINTENANCE

Total Productive Maintenance (TPM) is an approach, concept, tool or methodology originated in Japan and is considered the creator of this concept is an engineer Seiichi Nakajima. Nakajima [11] explains that there has long been a belief that maintenance is only an inevitable expense for the enterprise, and therefore sees the need to develop a maintenance approach aimed at optimizing business processes, reducing costs, improving product quality and increasing employee satisfaction. TPM, as already discussed in this paper, is one of the basic concepts on which world-class production is based.

The basic goals for which TPM was established were [11]: 1) maximizing the effectiveness of the equipment, 2) establishing a productive maintenance system throughout the lifecycle of the equipment, 3) involving all organizational units in the planning, design, using and maintenance of equipment, 4) actively involving all employees, from plant workers to top management and 5) promoting TPM and its importance through employee motivation. According to Williamson [12] TPM can be defined as a strategy for improving equipment and processes that integrates all elements of the maintenance system in a good way in order to achieve the highest level of equipment effectiveness. Arai [13] believes that the TPM methodology was created to support the Lean concept, as reliable and effective equipment is a key prerequisite for undertaking Lean initiatives in enterprises. The implementation of the TPM methodology is based on the achievement of the six basic goals explained in [14] (table 2).

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Table 2. The goals of applying the TPM concept [14].

Goal	TPM considerations
Productivity	• Reduced unplanned stoppages and breakdown improving equipment availability and productivity • Provide customization with additional capacity, quick change-over and design of product
Quality	• Reduce quality problems from unstable production • Reduced in field failures through improved quality • Provide customization with additional capacity, quick change-over and design of product
Cost	• Life cycle costing • Efficient maintenance procedures • Supports volume and mix flexibility • Reduced quality and stoppage-related waste
Delivery	• Support of JIT efforts with dependable equipment • Improves efficiency of delivery, speed. and reliability • Improved line availability of skilled workers
Safety	• Improved workplace environment • Realizing zero accidents at workplace • Eliminates hazardous situations
Morale	• Significant improvement in kaizen and suggestions • Increase employees' knowledge of the process and product • Improved problem-solving ability • Increase in worker skills and knowledge • Employee involvement and empowerment

As is the case with the WCM concept, Total Productive Maintenance in the literature is often represented by a temple that relies on the basic pillars, that is, the concept carriers. However, unlike WCM's 10 pillars, Total Productive Maintenance is based on the basic 8 pillars of the TPM temple shown in Figure 2.

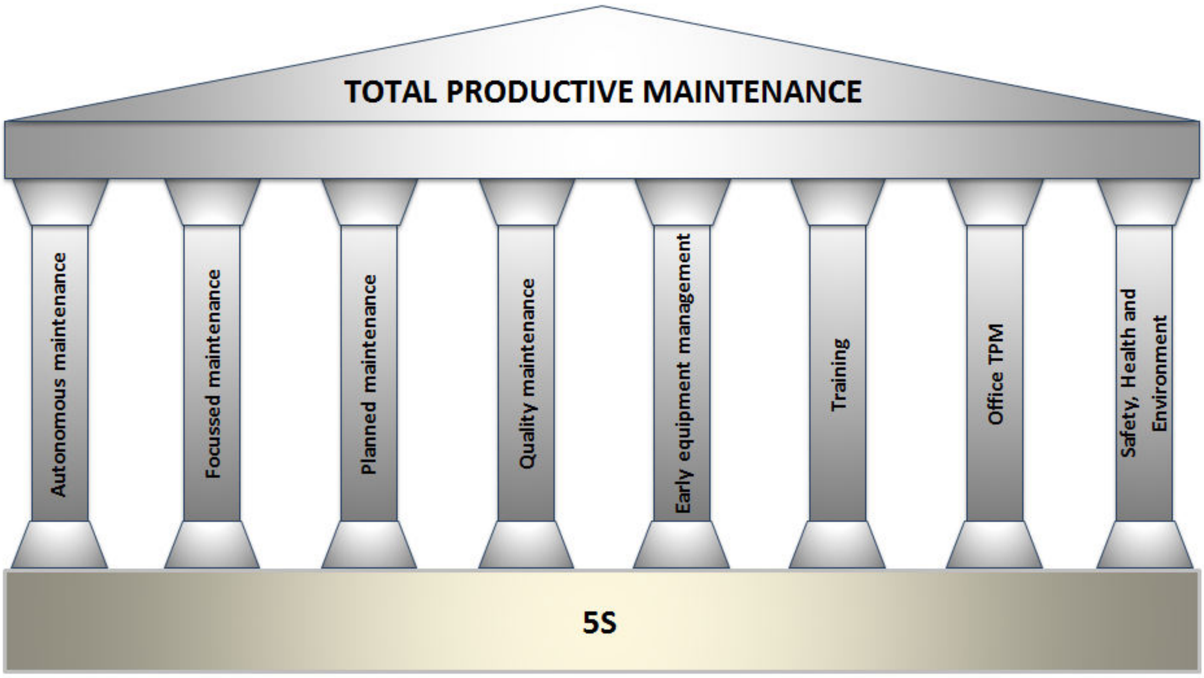

Figure 2. TPM temple and Pillars (adapted from [14]).

The basis for implementing the TPM concept is that the 5S method. The pillars of the TPM concept are briefly described below.

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I) Autonomous maintenance

Autonomous maintenance is the first pillar of the TPM concept and refers to the maintenance of production equipment by workers (operators) in the workplace. These are usually simple operations that workers do not have to go through long and demanding training. Such operations are actually those that are left to workers in the workplace so that maintenance workers have more time to perform much more complex maintenance activities. Autonomous maintenance activities are most commonly considered cleaning of machinery and equipment, lubrication, adjustment, control, etc. The rule is that workers, by means of visual management techniques, are at all times instructed on how and for what period they should carry out the maintenance activities of the equipment [15].

II) Focussed maintenance

The pillar of "Focused maintenance", "Focused Improvement", "Continuous Improvement" or "Kaizen" refers to the progress that is done gradually (step by step) and does not require large financial investments. Most of the ideas for advancement in the Kaizen approach come from the workers themselves who have the best knowledge of the situation in their workplace and the biggest problems that manifest themselves during work.

When it comes to TPM, Kaizen most often refers to [14]:

- a systematic identification and elimination of losses (application of Lean tools and techniques),
- identification, failure analysis and loss reduction using FMEA analysis,
- improving system efficiency and
- improving the Overall Equipment Efficiency (OEE).

FMEA (Failure Mode and Effect Analysis) analysis is one of the most known and commonly used methods for identifying and eliminating known and/or potential failures that occur during the process realization or on product [16]. When talking about Lean tools and techniques that are used to identify failures or maintenance issues, the most common methods are 5M (analysis of the factors that can cause the error: man, machine, material, method and or management), 5W + 1H (analysis of all the possibilities of an event: “What?”, “Who?”, “Where?”, “When?”, “Why?” and “How?”), 5 why method, Ishikawa diagram, etc.

III) Planned maintenance

Planned maintenance aims to ensure production without failure on machine and equipment. This type of equipment maintenance usually involves the work of highly trained engineers and maintenance operators [11]. In the WCM concept, Planned maintenance refers to the “Professional Maintenance” pillar. According to McKone, et al. [17], there are three basic elements of Planned maintenance, namely: 1) disciplined maintenance task planning, 2) monitoring of equipment status and process plans, and 3) aligning other activities with maintenance plans. The aforementioned elements of planned maintenance are closely related and interdependent, so that the implementation of these activities is done almost simultaneously [17].

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How well or badly the maintenance is planned is indicated by certain indicators. The most important indicator of the success of the planned maintenance is the already mentioned OEE (Overall Equipment Effectiveness), but also the equipment effectiveness can also be determined via the TEE (Total Equipment Effectiveness) parameter, which takes into account all available equipment operating time (including non-working days). There are other parameters that characterize the maintenance process, which are [18]:

- Mean Time Between Failures – MTBF,
- Mean Time to Repair – MTTR,
- Mean Down Time – MDT,
- Mean Up Time – MUT, etc.

In addition to the above parameters, the success of the implementation of maintenance activities can be monitored by the number of cancellations, costs, etc.

IV) Quality maintenance

Quality maintenance refers to ensuring production without the appearance of defects (write-offs) on products. This pillar of the TPM concept plays an important role in reducing production costs, which are significantly reduced when defects occur. Also, the Quality maintenance is important in that a non-compliant product must in no way reach the customer. In this case, proper and timely maintenance activities have the task of preventing product defects caused by the malfunctioning of production equipment [15]. Some of the methods and techniques that are often used to provide equipment functionality and product quality are [9]: QA matrix, FMEA analysis, PM analysis, 4M and 5M analysis, OPL, etc. Maintenance quality activities often refer to the checking and calibration of control and measuring equipment, the correctness of which directly affects the quality of the product.

V) Early equipment management

TPM's fifth pillar is "Early Equipment Management". This concept holder refers to the application of accumulated knowledge in the design and manufacture of production equipment, in such a way as to reduce the possibility of errors during its exploitation [19]. Many authors also see “Early Product Management” as part of this pillar, as in the WCM concept, but in the long run it can be said that the two activities are closely related and interdependent. Also, one of the primary goals of Early Management is to improve the Overall Equipment Effectiveness (OEE) [20].

VI) Training

"Training" is the sixth pillar of the TPM temple and refers to the training of employees and the acquisition of key skills and knowledge to perform work activities, as well as skills and knowledge related to the implementation of the TPM concept. In this case, the training is primarily for maintenance operators, but to some extent for all workers in the production facility, with the aim of successfully conducting autonomous maintenance activities. The identification of training needs in the TPM concept is usually done in three basic phases [21]: 1) identifying the required skills and knowledge to perform certain activities, 2) assessing the current level of skills and knowledge of employees, and 3) planning and delivering training.

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VII) Office TPM

Office TPM aims to increase the efficiency and productivity of administrative functions while identifying and eliminating losses. The basic task of this pillar is to support production and maintenance activities. TPM administration contributes to the realization of business processes by providing accurate and timely information regarding the implementation of business processes and has its contribution to business decision making [22].

VIII) Safety, Health and Environment

The last, but perhaps most important pillar of the TPM concept for employees is Safety, Health and Environment. As the name implies, this pillar aims to provide a safe and healthy workplace for employees, as well as to reduce the adverse environmental impact of manufacturing activities. According to [15], the main objectives of this TPM pillar are:

- zero accidents,
- zero cases of health impairment and
- zero fire.

Along with the mentioned goals, one can also mention elimination of worker overload (Muri), avoiding major physical exertion, reducing stressful situations, eliminating any kind of mobbing in the workplace and preventing environmental damage. In this case, enterprise management is responsible for developing employee awareness of the importance of implementing this pillar [23].

3.1. The barriers that has an impact to the implementation of the TPM concept

During the implementation of the TPM concept, management and employees face many problems. A large number of papers can be found in the literature where authors analyze problems or the so-called barriers that had a negative impact and slowed down the implementation of the TPM concept in enterprises.

The authors Singh et al. [24], based on a comprehensive literature review, found that when implementing the TPM concept, there are generally 11 basic barriers, which are: 1) lack of support and understanding by management, 2) insufficient resources (money, people, time, equipment, etc.), 3) Insufficient understanding of methodologies and TPM philosophy by operational mangement, 4) Barriers within individual business units, 5) Consideration of TPM activities as a additional commitments/threats, 6) Lack of time for autonomous maintenance activities, 7) Pressure from the manufacturing sector, 8) omitting important implementation steps to complete the process sooner, 9) lack of adequate training, 10) frequent shifts and disagreements in top management, and 11) resistance on change.

In paper [25], the authors identified 21 barriers to TPM implementation, namely: 1) lack of commitment from top management, 2) resistance towards changes, 3) unwillingness to engage resources, 4) work culture, 5) employee resistance. 6) long-term commitment of management and employees, 7) labor costs, 8) non-involvement of non-management personnel, 9) lack of appropriate remuneration mechanism, 10) lack of knowledge of TPM, 11) need for training, 12) failure to conduct a “pilot” study , 13) improper team forming, 14) relation to production, 15) repairs are the "drive" of

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maintenance, 16) inability to plan for a design change or maintenance policy change, 17) maintenance management process, 18) design change issues, 19) unavailability of standard operating procedures, 20) tools and instruments and 21) storage of large quantities of inventory.

Differently defined barriers affecting TPM implementation can be found in the literature, but certainly most of them are repeated in many cases, only the authors have named them differently. Based on a review of the relevant literature Attri, et al. [26] classified all barriers affecting TPM implementation into 5 core groups, namely: 1) Behavioral barriers, 2) Technical barriers, 3) Operational barriers, 4) Strategic barriers, and 5) Human and cultural barriers.

The best way to identify barriers is certainly directly from experience or from practice. At the factory that received the highest World Class Award for the implementation of the TPM concept by JIPM, management and employees identified a total of 45 barriers that affect the implementation of this concept. The considered factory (plant) has received the highest World Class award for implementing the TPM concept awarded by JIPM, and this award so far received only 20 factories in the world in the last 40 years. The identified barriers that affect the implementation of TPM concept defined in this factory are shown in table 3.

Table 3. Barriers affecting TPM implementation identified by factory employees awarded with top World Class award for TPM concept implementation.

Barrier group, g_i	*Barriers to successful TPM implementation*
1. Communication and strategy	1. Open and honest communication in organization 2. Pillar and team boards have important role in effective communication 3. Strong visual management 4. Strong TPM manager driving the program 5. Strong TPM office offering full support to employees 6. Clear management and organization plans for the future 7. Promotion of ZERO culture 8. Strong focus on talented people recruitment 9. Optimal organizational structure in all departments 10. Permanent and well-established auditing system 11. Steering team is taking leading role in organization development 12.Lack of job security 13. Contribution to society
2. Senior management role	14. Support of senior management 15. Committed organization leader - leading by example 16. Commitment of senior management 17. Strong support from central (company) TPM organization 18. TPM program success is depending on full involvement of middle management
3. Employees participation	19. Participation of all employees 20. Development of team culture 21. Full empowerment of all employees 22. Culture of one team between maintenance and production 23. Skilled maintenance operators

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Barrier group, g_i	*Barriers to successful TPM implementation*
	24. Skilled production operators 25. Innovative spirit in the organization/company 26. Freedom with accountability as company value
4. Effective organization goals	27. Good selection of KPIs 28. Clear company strategy 29. Effective data collection 30. Focus on OHS and environment
5. Education and training	31. Permanent education and training of all employees 32. Well established technical trainings 33. Understanding of equipment and process base condition 34. Development of the in-house trainers 35. Technical background of shop floor employees 36. Technical background of the middle management 37. Permanent training of all employees related to TPM methodologies
6. Structured approach to TPM implementation	38. Step by step approach in problem solving 39. Establishment and support of TPM office 40. Effective and detailed PM plans development 41. Effective and detailed AM plans development 42. Support of PM to AM 43. Effective use of TPM methodologies
7. Reward and recognition	44. Strong reward and recognition system 45. Fair treatment of all employees in the company

The survey conducted at the factory involved employees from different hierarchical levels of the organization, but also employees with different experience and from different organizational sectors. The task of the respondents was to evaluate how much the every barrier affects the implementation of the TPM concept on a scale [1–7]. Of the total number of respondents, 10% have completed high school, 15% have a Bachelor's degree and 75% have a Master's degree. Regarding the work experience of employees in the implementation of the TPM concept, 5% of the respondents have less than 2 years of experience, 34.5% have 2 to 5 years of experience, 42.5% between 5 and 10 years and 18% more than 10 years of experience. Of the total number of respondents, 13% are currently in the position of operator in the manufacturing facility, 62.5% are in middle management, and 24.5% are in senior management. In terms of organizational structure of respondents, 30% are from the manufacturing sector, 20% from the maintenance sector, 17.5% from the quality sector and 32.5% from other sectors in the company (logistics, finance, logistics, etc.).

METAHEURISTICS AND GA

Large-scale optimization problems are characterized by the fact that finding a unique and optimal solution takes a long time and requires a very complex procedure and calculation. There is no single definition of metaheuristics in the literature, but metaheuristics can be considered as a group of search algorithms that solve complex optimization problems based on general heuristic principles [27]. On the other hand, Talbi [28] defines metaheuristics as a higher-level methodology that can be used as a

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guide for devising fundamental heuristics when solving specific optimization problems. The same author concludes that modern metaheuristic algorithms have been developed with the aim of conducting a global search, highlighting their three basic advantages: faster problem solving, solving of large-scale problems, and obtaining robust algorithms. Luke [27] defines metaheuristics as advanced heuristics or higher level heuristics, and unlike classic heuristic methods, they can be applied to a number of different optimization problems.

The goal of applying metaheuristics is to find some acceptable solution, which should be close to the optimal solution.

Metaheuristics usually have an iterative form, which means that one or more initial solutions are refined through multiple iterations to arrive at a suboptimal solution. The basic three steps of implementing these methods are [29]:

1) generating of one or more initial solutions,
2) developing the initial solutions until the stopping criteria is met and
3) the best solution from the second step is obtained as the output of the algorithm.

Generating of one or more initial solutions is usually done randomly or so that the initial solution is admissible but not necessarily suboptimal (there is very little possibility). The initial solution is repaired iteratively until the stopping condition is satisfied, which may be, first of all, the number of iterations, time, expected quality of the solution (value of the objective function), etc. The last, third, step of applying metaheuristic methods is the analysis of the obtained solution, which is actually a way out of the algorithm [29].

Today, there are a large number of metaheuristics that have been developed with the aim of solving problems in various research domains. Some of the commonly used methods of this type are various Evolutionary algorithms, such as Genetic Algorithm (somewhere as a Genetic Algorithms), Tabu Search, Local Search, Variable Neighborhood Search (VNS) method, Simulated annealing, Bee Colony Optimization, Ant Colony Optimization and many more.

Below are the basics and explain the problem solving procedure using the Genetic Algorithm, which belongs to population-based metaheuristics. The founder of the GA method is Holland [30] in 1975, but he established the basics of this method in 1962, and it is still used today to solve various types of optimization problems. Holland's idea was to base his method on the basic principles of adaptation and reproduction of organisms in nature, mimicking three basic evolutionary processes: 1) selection, 2) crossover and 3) mutation. GA has been applied in the literature in various ways, with some variations and adjustments to the considered problem, but it can be said that all modifications are based on the basic (canonical) algorithm, whose scheme, ie the problem solving procedure is shown in Figure 3.

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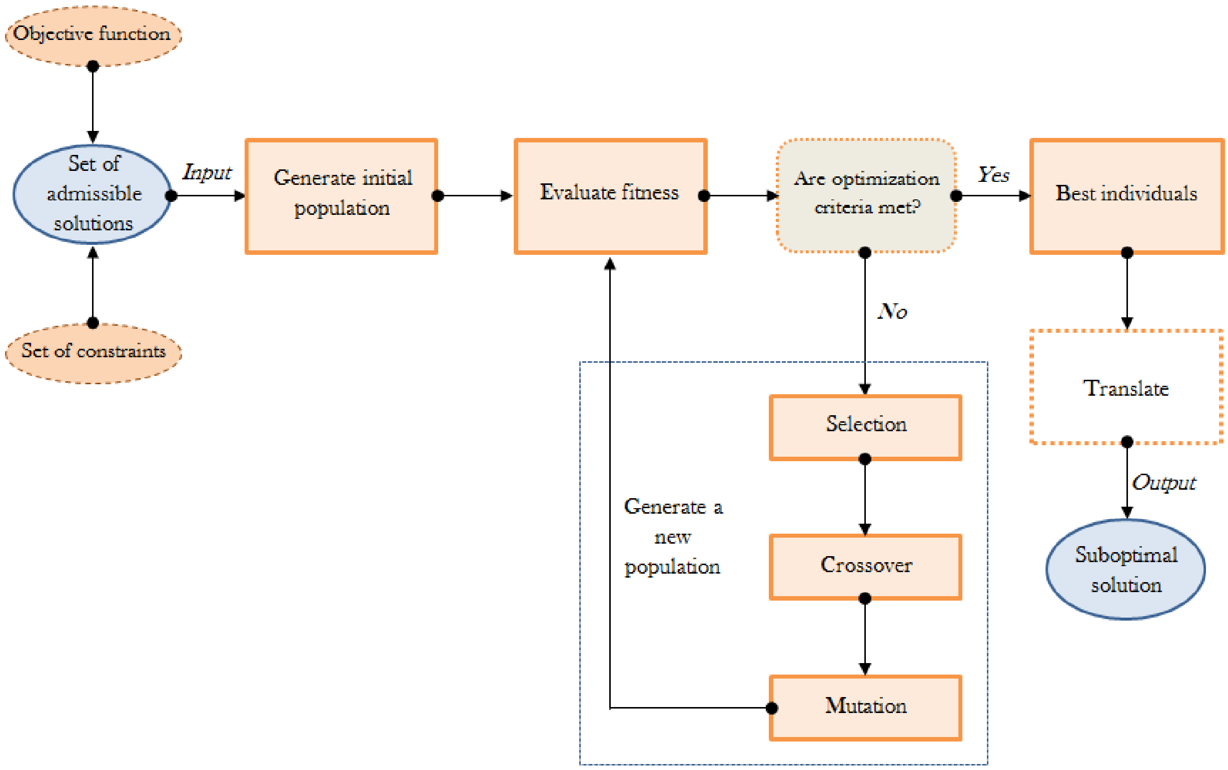

Figure 3. Basic procedure for solving optimization problems using GA (adapted from [31]).

Before the beginning of solving any optimization problem using GA, it is needed to define a objective function (one or more) and define a set of constraints. However, even before defining these parameters, it is necessary to understand how space search is performed, which gives major recognition to each metaheuristic. The parameters of the search space are coded in the form of strings, called chromosomes. A set of multiple strings is called a population. In other words, the population represents a set of different points in the search space. Each chromosome is described by a value that indicates its quality as a considered solution. This value is called fitness, that is, the degree of goodness, which actually represents the value of the objective function for the observed chromosome [32]. In another way, the objective function can be defined as the adaptation function of each individual (chromosome) to the defined objective function [29].

4.1. Suggested algorithm

The problem solved in this paper is set as a p-median problem. This type of problem is defined by Hakimi [33] and is based on finding p points (objects) around which are n points (objects) grouped. This type of problem is best suited to the location select problem, where specific points (predefined number) are selected for points, and based on that, other points in the search space that are conditionally closest to any point (based on defined criteria) are selected. An example of a p-median problem is shown in Figure 4.

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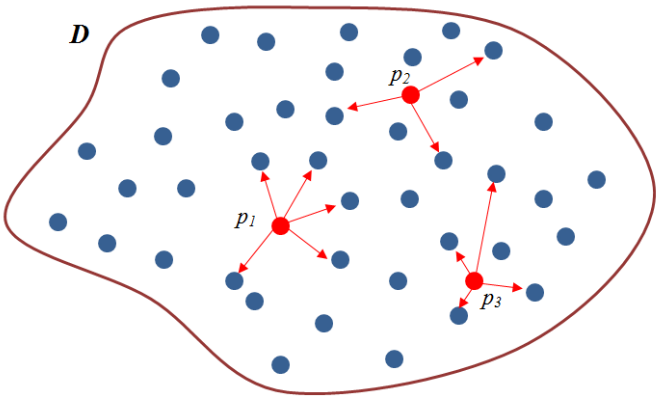

Figure 4. Grouping n points around three p points in the set of admissible solutions D.

When the location selection problem is set as a p-median problem, locations are usually selected based on the location distance from the p location, but also based on some other criteria. In this case, the distance of the n points/barrier with respect to the p point/barrier is represented by the interdependence of the barriers. In fact, the estimates determine how much the implementation of some barrier b_j affects the implementation of all other barriers b_k. This determines the distance between all barriers. As the second optimization criterion, the importance of each barrier for the implementation of the TPM concept evaluated by employees was adopted.

The suggested algorithm is implemented in 5 steps:

Step 1:

a) assessing the importance or impact V_j of each barrier b_j to TPM concept implementation and
b) assessing the barrier interdependence Z_{jk}, that is, to what extent the implementation of the barrier would b_j facilitated the implementation of each barrier b_k.

Step 2:

a) Normalization of value V_j was performed by applying a linear normalization procedure:

$$r_j = \frac{v_j}{\max_j v_j}, \text{ for benefit type, and} \tag{1}$$

$$r_j = 1 - \frac{v_j}{\max_j v_j}, \text{ for cost type.} \tag{2}$$

b) Normalization of value Zjk was performed by applying a linear normalization procedure:

$$n_{jk} = \frac{z_{jk}}{\max_k z_{jk}}, \text{ for benefit type, and} \tag{3}$$

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$n_{jk} = 1 - \frac{z_{jk}}{\max_k z_{jk}}$, for cost type. (4)

Step 3: Defining the objective function:

1) Maximize the impact of barriers r_j on implementation of TPM.

$$\max \sum_{j=1,\ldots,J,\ \ k=1,\ldots,K} r_j \tag{5}$$

2) Maximize barrier interdependence n_{ik}.

$$\max \sum_{j=1,\ldots,J,\ \ k=1,\ldots,K} n_{jk} \tag{6}$$

Since the values were normalized in the previous step, both objective functions are benefit type, and therefore the maximum of the function is determined.

Step 4: Setting priorities for eliminating barriers using the Genetic Algorithm within the software *Matlab R2018a*.

Step 5: Presentation and analysis of obtained solutions.

5. ILLUSTRATIVE EXAMPLE

In the Step 3, the objective functions and parameters are specified according to which GA selection was performed, namely:

a) number of individuals in the population: 50
b) stop criterion: 2.500 iterations,
c) roulette selection,
d) random selection of points of crossover, and
e) random selection of genes that mutate.

First, on the basis of the parameters entered and set objective functions, GA is used to select the optimal points (Step 4), which are most satisfying for both goal functions. Figure 5 shows a Pareto front diagram that shows how well the selected p points satisfy both the objective functions (fitness functions).

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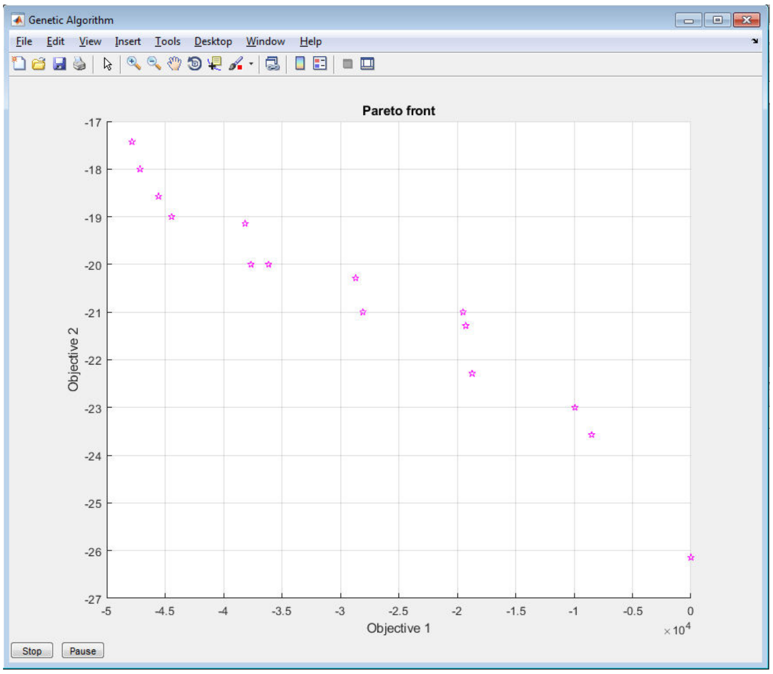

Figure 5. Selected p barriers and their fitness functions 1 and 2.

Then, from the best points, it is necessary to select a certain number that equally satisfies both objective functions (Step 4). In this case, 5 points were selected (Figure 6). These points actually represent those barriers whose implementation greatly facilitates the implementation of some other barriers.

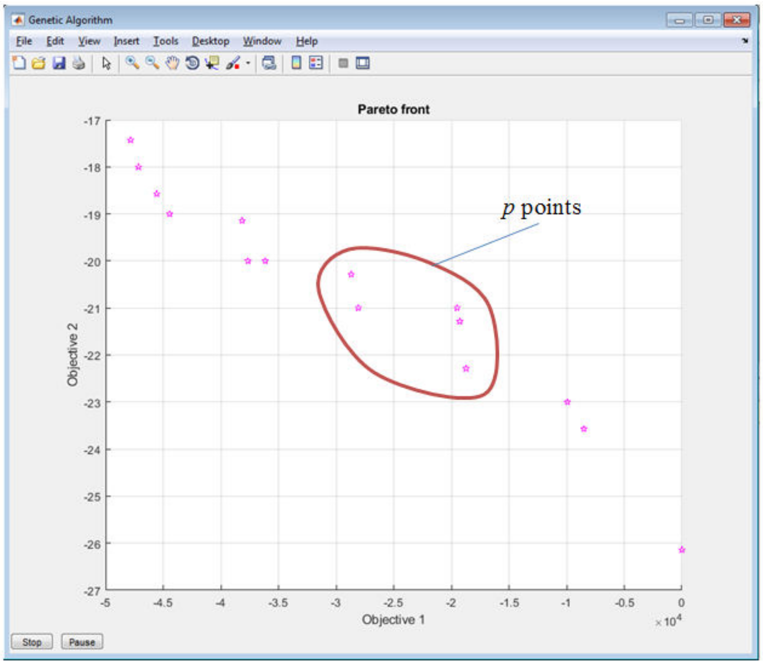

Figure 6. Selection of five p points (barrier) whose value equally satisfies both objective functions.

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It should be noted that other p points can be analyzed, but each of these points does not sufficiently satisfy one of the two objective functions.

To each of the selected p points, by applying GA are joined points that grouping around it. In this case, these points are barriers. Table 4 shows the selected p points as well as n points that are grouped around it (Step 5).

Table 4. Barriers that have the greatest impact on the implementation of the TPM concept (p barriers) and barriers that are easier to eliminate if p barriers are first eliminated.

	Set of barriers 1	Set of barriers 2	Set of barriers 3	Set of barriers 4	Set of barriers 5
***p* barrier**	Effective use of TPM methodologies (b_{43})	Open and honest communication in organization (b_1)	Support of senior management (b_{14})	Technical background of the middle management (b_{36})	Permanent education and training of all employees (b_{31})
Barriers grouped around the *p* barrier	Strong visual management (b_3)	Pillar and team boards have important role in effective communication (b_2)	Clear management and organization plans for the future (b_6)	Strong TPM office offering full support to employees (b_5)	Skilled maintenance operators (b_{23})
	Step by step approach in problem solving (b_{38})	Strong TPM office offering full support to employees (b_5)	Promotion of ZERO culture (b_7)	Development of team culture (b_{20})	Skilled production operators (b_{24})
	Support of PM to AM (b_{42})	Promotion of ZERO culture (b_7)	Steering team is taking leading role in organization development (b_{11})	Focus on OHS and environment (b_{30})	Effective data collection (b_{29})
		Development of team culture (b_{20})	Commitment of senior management (b_{16})	Support of PM to AM (b_{42})	Understanding of equipment and process base condition (b_{33})
			Participation of all employees (b_{19})	Effective use of TPM methodologies (b_{43})	Development of the in-house trainers (b_{34})
			Clear company strategy (b_{28})		Effective use of TPM methodologies (b_{43})

Table 4 shows that the p barriers b_{43}, b_1, b_{14}, b_{36} i b_{31} are in fact the barriers that largely satisfy both objective functions. Other barriers, that is, grouped around each of them, are barriers that would be easier to eliminate if the p barriers were eliminated first. There is a case where one of the barriers grouped around one p barrier is simultaneously grouped around another. This means that the elimination of a recurring barrier depends on both p barriers. In this way, enterprise management can have an insight into which barriers should be eliminated primarily, respecting the importance of barriers as well as their impact on eliminating other barriers.

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6. CONCLUSION

The problem of identifying the most important barriers, in particular those barriers that have the greatest impact on the implementation of the TPM concept, is considered in the paper. In addition to the major impact barriers, the Genetic Algorithm identified barriers that could be eliminated more easily if the highest impact barriers were first eliminated. The criteria on which the selection of the most important and the barriers that directly depend on them are made are: 1) the importance of barriers to the implementation of the TPM concept, and 2) the extent to which eliminating one affects the elimination of other barriers and vice versa. The application of a useful artificial intelligence tool, such as the Genetic Algorithm, can greatly facilitate enterprise management in the decision-making process, which is actually one of the goals of this paper. However, any metaheuristic or exact decision making method can serve management solely as an aid to decision-making, but by no means something that should be kept without first thorough analysis.

The basic prerequisite for successful implementation of any decision-making method is sufficiently accurate input data. In this case, the data used for the GA analysis in this paper were obtained by interviewing employees of a company that has received the highest World Class Award for implementing the TPM concept, which gives this analysis special significance.

Based on the application of the Genetic Algorithm to solving the problem under consideration, the most important barriers that affect the implementation of the TPM concept are the support of top and middle management, the proper use of the TPM methodology, open and honest communication within the organization, as well as constant education and training of employees. It should be noted that these barriers are by far the most important, that is, only when considering the above two criteria. If some other criteria were considered, it is clear that the results would be different.

Future research directions should focus on the application of the Genetic Algorithm, but some other metaheuristics, as well as Multi-Criteria Decision-Making methods, to solve this and similar problems. Different ways of solving problems need to be explored by introducing the premise that the considered criteria do not have the same importance as well as decision makers. Also, it is necessary to analyze the possibility of introducing some other optimization criteria in this problem solving. Certainly, a research area such as the TPM concept has plenty of room for analyzing and conducting scientific research.

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